VOLUME 61 [W. B. No. 1100] NUMBER 3

MONTHLY WEATHER REVIEW

MARCH 1933

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UNITED STATES DEPARTMENT OF AGRICULTURE
WEATHER BUREAU
WASHINGTON, D.C.

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MONTHLY WEATHER REVIEW

Editor, W. J. HUMPHREYS

Vol. 61, No. 3
W. B. No. 1100

MARCH 1933

Closed May 3, 1933
Issued June 22, 1933

THE DIURNAL VARIATION OF FREE-AIR TEMPERATURE AND OF THE TEMPERATURE LAPSE RATE [1]

By J. C. Ballard

[Aerological Division, Weather Bureau, Washington, D. C.]

I. THEORETICAL DISCUSSION OF THE SUBJECT

A. FACTORS PERTAINING TO TEMPERATURE CHANGES AT THE SURFACE AND IN THE LOWER ATMOSPHERE

1. *Solar radiation.*—It is well known that on the average the temperature at the surface begins to increase shortly after sunrise, reaches a maximum, and then falls until about sunrise the next day. A large part of the increase is caused by the absorption of solar energy, and its magnitude depends mainly upon the following factors:

(*i*) Amount, intensity, and kind of radiation reaching the surface, which in turn depends upon—

(*a*) The quality of the radiation reaching the outer limits of the atmosphere, which quality changes at least with the period of sun spots,

(*b*) The normal intensity of the radiation at the outer limits of the atmosphere. At a given place, this intensity changes with the time of day, with the season and with any variations there may be in the solar constant,

(*c*) The absorption of the incoming radiation by carbon dioxide, ozone, water vapor, dry air, etc., in the atmosphere,

(*d*) The depletion of the incoming radiation by reflection, and scattering by dust, haze, air molecules, clouds, etc.,

(*e*) The length of the day,

(*f*) If on land, the height of the surface above sea level, since it determines to some extent the amount and composition of the overlying atmosphere.

(*ii*) Albedo of the surface, which depends upon—

(*a*) The nature of the surface, such as water, type of soil, snow covering, vegetation, etc.,

(*b*) The angle of inclination of the incident radiation.

(*iii*) Specific heat of the surface material which differs widely between water and soil.

(*iv*) Rate of loss of heat, depending upon—

(*a*) The temperature of the radiator,

(*b*) The nature of the radiating surface,

(*c*) Conduction by the surface material and between the surface and adjacent air,

(*d*) Thermal and eddy convection,

(*e*) Change of phase of water,

(*f*) Advection,

(*g*) Rate of return of heat from the air, reflection by under surfaces of the clouds, etc.

In the lower atmosphere (sea level to 3,000 meters) the percentage of absorption of the incoming solar radiation is, to a large extent, a function of the water-vapor and carbon-dioxide content. Pure dry air in this region absorbs but little incoming radiation of any kind. That which it would absorb has already been taken out by the air above. The carbon-dioxide content of the atmosphere is fairly constant at all times and places. The water-vapor content, however, varies widely with time of day, season, and geographical location. Since it has been quite definitely established that the power of absorption of air for solar radiation increases with increase in water-vapor content, it is obvious that this absorption must be greatest, other things being equal, where and when the absolute humidity is greatest. Likewise, water vapor is a good radiator. Therefore, so far as atmospheric absorption and radiation alone are concerned, we should expect to find the greatest diurnal temperature ranges during seasons and at stations where the water vapor content is relatively large.

2. *Reradiation between the ground, clouds, and atmosphere.*—The radiation involved here is a long-wave-length type of which the air as a whole is more absorptive than it is of solar radiation. The rate at which any particular sample (of air or surface) radiates depends mainly on its absolute temperature and its nature, that is, kind of substance, state (gaseous, liquid or solid), conductivity, etc.

The absolute temperature of the sample depends upon its heat capacity and the amount of heat it absorbs whether supplied by radiation, convection or otherwise, and the amount of heat which, in the meantime, it similarly loses.

Reradiation keeps the temperature of the radiating body lower than it otherwise would be. Evidently, absorption and reradiation jointly produce a diurnal range of temperature both in the free air and at the surface. Since the temperature difference between the ground and the air next to it usually is much greater than that between two adjacent air layers, the greatest exchange of heat per unit area and the greatest diurnal range of temperature takes place near the surface.

Since exchange of heat by radiation between two like objects results in a net loss by the warmer and gain by the cooler, it follows that this process tends always to decrease the numerical value of the average temperature lapse rate in the free air. That is, it tends to bring the air of different levels to the same temperature.

This subject has been discussed by, among others, D. Brunt (5), who obtains the following relationship between change of lapse-rate with height and temperature change with time:

$$\frac{\delta T}{\delta t}=K_r\frac{\delta^2 T}{\delta Z^2} \qquad (1)$$

where T = temperature, t = time, Z = height, and K_r, which is analogous to the conductivity coefficient in the

[1] A good historical sketch of studies made up to 1912 of the diurnal variation of temperature is given by Josef Reger (1). A later study and one which seems to be better supplied with data than these previous studies was made by Hergesell (2) in 1922. The important early work done on this subject in the United States was carried out at Blue Hill (3), and at Mount Weather (4).

similar well-known differential equation of heat conduction in a solid, is defined by the expression

$$\frac{\delta E}{\delta T}\frac{T}{p_w}\frac{b}{60\rho C_p}.$$

In the latter expression E is the amount of radiation of "wave-lengths within which water-vapor amounting to 0.3 mm of precipitable water radiates like a black body", T and p_w are, respectively, the mean absolute temperature and mean vapor-pressure in millibars within a layer containing this quantity of precipitable water, b a constant, ρ the density, and C_p the specific heat at constant pressure, of the air. Equation 1 is obtained in this relatively simple form only if K_r is considered constant with altitude.

3. *Vertical convection.*—There are two types of vertical convection, (*a*) thermal and (*b*) mechanical turbulence. Both cause mixing of the air and thus transfer heat. In addition, both produce temperature changes by dynamical processes and by helping to change water vapor to liquid or solid water and the reverse. In so far, then, as convection has a diurnal period, to that extent it influences the diurnal temperature march both at the surface and aloft.

Thermal convection on the large scale that leads to the development of cumulus clouds is more or less irregular and will not be further considered here. Mechanical turbulence is more generally present, however, and plays an important role in the diurnal heating of the air up to certain levels.

Due to its flow over irregular surfaces there always is considerable eddy motion and turbulence in the air and, consequently, an absence of persistent instability in the layers so disturbed. Furthermore, some air which was stable in its initial position is constantly being carried upward or downward mechanically by turbulence. If the lapse rate exceeds the adiabatic for the air in question, that which is carried upward will always be at a higher temperature than the immediately surrounding air, therefore, lose heat to it and decrease the lapse rate. Conversely, when the lapse rate is less than the adiabatic, air carried upward always is cooler than the surrounding air, from which it takes heat and thereby increases the lapse rate. In each case the lapse rate is rendered more nearly adiabatic.

Evidently, heating of the air aloft by transfer of heat from the ground by turbulence normally can occur during only a limited time through the day, and extend up only to moderate heights, because for this process to occur the average lapse rate between the level heated and the surface must be superadiabatic. An inversion immediately off the ground prevents convection because any turbulence then starting at the ground is almost immediately damped-out. It should be emphasized, however, that the temperature at any level can be raised due to the vertical transfer of heat by turbulence even though the lapse rate is not as great as the adiabatic. For example, consider a level such that the lapse rate above the level is less than the lapse rate below it. The motion downward serves to heat the air at the level in question and the motion upward serves to cool it. If equal masses are moved upward and downward across the level, it is evident that the effect of the heating will exceed the effect of the cooling, and the temperature at the level will rise.

Taylor (6), Brunt (5), Richardson (7), Schmidt (8), and others have treated the subject of heat transfer by turbulence and arrived at various quantitative expressions. According to Brunt (5), the heating produced by turbulence can be approximately expressed by the equation,

$$\frac{\delta T}{\delta t}=K\frac{\delta^2 T}{\delta Z^2} \tag{2}$$

where T, t, and Z are the same as in equation 1, and K is a measure of the capacity of the air for being heated by turbulence. Humphreys (9) has shown how this coefficient may be related to wind and rate of evaporation changes.

4. *Advection.*—The largest and most rapid temperature changes in the free air over a given place are caused by the horizontal transportation of heat in the passage of cyclonic disturbances, etc. These changes, however, are so irregular that with sufficient data they should cancel out. In cases where the observations are insufficient in number, or where a preponderance of them was obtained in some particular type of changing weather conditions, the effects of this method of heat transfer appear in the results.

Diurnal variations of wind, such as occur on a sea coast, a mountain slope, or in a valley, produce important effects on the diurnal variation of temperature.

Besides transporting heat mechanically, winds serve in at least two other important ways to affect the diurnal variation of temperature. One is by changing the degree of turbulence, the effects of which have already been discussed, and the other by increasing the rate of evaporation. The latter is a cooling process of considerable effect over moist surfaces.

5. *Changes of phase of water.*—The heat content of water differs so greatly with the phase that any change thereof is an important factor in heat transference. This difference is greatest between the solid and vapor and the liquid and vapor phases. That these changes may be important in the present problem, they must have a diurnal variation, and such diurnal tendencies do exist in the formation of clouds, rain, dew, frost, and in evaporation.

The diurnal tendency to the formation of clouds and rain is most pronounced at certain average levels and in certain seasons, as illustrated by the development of cumulus clouds on summer afternoons. These processes produce a direct effect on the diurnal temperature march in the region of formation and an indirect effect at all levels below it and for some distance above.

The formation of dew and frost, occurring mainly at night, is accompanied by the liberation of considerable heat, and thus has a tendency to reduce the fall in temperature. The evaporation of this dew and frost, as well as the evaporation of surface moisture, during the day has a tendency to reduce the temperature rise of the surface in two ways: (1) Much heat is absorbed in the actual evaporation, and (2) the increased water vapor content of the air serves to increase the depletion of solar energy by the air.

The processes just described, no doubt, have a very important part in maintaining the temperature balance in the lower atmosphere, serving specifically to decrease the diurnal range near the surface and to increase it in the free air.

6. *Conduction of heat between the ground and adjacent air.*—The amount of heat transferred from the surface to the adjacent air by conduction is a function of the rate of flow of heat, which depends mainly upon the temperatures, thermal conductivities, vertical temperature gradients, and specific heats of the surface material and of the adjacent air and indirectly upon the roughness of the

surface. This amount is considerable when the ground is very hot and the wind is strong enough to maintain, by mixing, a large temperature difference between the surface and the adjacent air.

B. THE DIURNAL RANGE OF TEMPERATURE

It is obvious that the diurnal range of temperature at any level depends upon the combined effect of all the factors discussed in I, A, and others not specifically mentioned. The relation between these factors and the magnitude of the range can be more clearly seen, however, if a coordinated discussion is given under the headings indicated in the following paragraphs.

1. *Water vapor.*—Water vapor in the air, as is well known, decreases the diurnal range at the surface by decreasing the maximum and increasing the minimum temperatures. The maximum temperature is decreased largely (1) by the depletion of solar energy in passing through the water vapor, and (2) by the evaporation of surface moisture. The minimum is increased (1) by the absorption of ground radiation, and (2) by the condensation of water vapor to form dew or frost.

At levels well above the surface in an atmosphere which is fairly uniformly humid throughout, water vapor presumably should serve to increase the diurnal range because moist air is a much better absorber and radiator than dry air.

The total effect of water vapor, then, presumably, is to decrease the diurnal temperature range at or near the surface and to increase it beyond certain levels above the surface. This should be true quantitatively as well as qualitatively; hence, other things being equal, the diurnal range at the surface should be least at stations where the amount of water vapor in the atmosphere is greatest and at these stations the rate of decrease of range with altitude would be least. This presumption appears to be supported by the data presented later.

2. *Nature of the surface.*—The nature of the surface largely influences the diurnal temperature range to a considerable height. Thus, the range is much less over snow, a good reflector, than over bare soil, a much better absorber. Hence in mid latitudes the range generally averages less during winter than summer.

Also, since wet surface material has a greater specific heat than dry its temperature is raised less for the same amount of energy absorbed, and due to its lower temperature it cools more slowly. The effect of this factor therefore, most pronounced over a body of water, is to decrease the diurnal range.

Evidently too, the temperature at a ground surface, and its diurnal range, are materially affected by the conductivity of the soil, in such manner that the higher the conductivity the less the range.

3. *Mean air displacement.*—The observational data for a diurnal study often can be so treated that the warming or cooling that accompanies the passage of cyclones and anticyclones does not appreciably affect the *direction* of the average diurnal change at any hour. The magnitude of the average diurnal range, however, is altered appreciably, if not materially, by such disturbances when frequent. Thus, frequent periods of decreasing or low temperature, resulting in a large number of days during which the temperature rises only a relatively small amount, reduce the average diurnal range. Conversely, it is increased by frequent warming or warm periods.

The conditions just described and their attending effects are more or less irregular in frequency and magnitude. The average direction, velocity, and origin of the wind also have an important bearing on the magnitude of the diurnal range. Air coming from a relatively warm region, as over land on clear summer days, serves to augment the effect of solar radiation during the day, and when this wind decreases in velocity or stops at night, the diurnal range is increased. A system of land and sea breezes, however, decreases the diurnal range.

At stations where upslope winds or downslope winds are prevalent the effects of dynamical cooling or warming are important. Nightly air drainage at mountain and valley stations also is important, as it causes a greater diurnal range at the surface in the valleys than on the slopes.

4. *Number of hours of sunshine.*—The number of hours of sunshine varies greatly with the season in high latitudes, and, generally, with latitude, on even the same day. The relation between the diurnal range and the number of hours of sunshine is quite obvious, but attention must be called to the effect of this relationship in the two seasons, spring and autumn. In the northern hemisphere the average duration of sunshine in the spring months—March, April, and May—is longer than in the autumn months, September, October, and November. This difference increases with latitude. Hence, other things being equal, the diurnal range should be greater in spring than in autumn, and the difference in range between the two seasons should be greater, the greater the latitude. The effect of this factor upon the diurnal range is in the same direction at all levels.

5. *Miscellaneous.*—While the factors already named have the greatest controlling influence upon the diurnal range, sometimes certain others, such as cloudiness, smoke, haze, dust, height of station above sea level, and physiographic environment, also are important.

Thus, near industrial centers the average amount of smoke is considerably greater than in the open country, resulting in a great decrease in the amount of solar radiation reaching the surface. The effect on the diurnal temperature range is obvious. This condition generally is most pronounced in winter.

As to height, the higher a station the more intense, in general, the sunshine, and the less the sky radiation, and therefore the greater the diurnal range.

C. THE DIURNAL VARIATION OF TEMPERATURE LAPSE RATE

Since reradiation, as previously explained, tends to remove all "kinks" from the temperature-height curve, while turbulence tends to produce an adiabatic lapse rate, therefore each helps to determine the temperature change at any particular level. Hence, in so far as these two phenomena themselves have a diurnal variation they tend to produce a like variation in the temperature lapse rate.

If the temperature changes occur substantially independently of the lapse rate, any change in the latter with time is a function of the variation of the magnitude of the diurnal range with altitude and of the change of phase of the diurnal temperature period with altitude. Thus, if there is no variation of these 2 controlling factors with altitude between any 2 levels, there will be no diurnal variation of the average lapse rate between these 2 levels. On the other hand, when conditions are such that the temperatures at any two levels, between which there is a positive lapse rate, are rising or falling at unequal rates, it is evident that the lapse rate between the levels will correspondingly change. When the temperature at the lower level is rising faster than the temperature at the upper level, the average lapse rate between the two will be

increasing; and when the reverse conditions prevail, the lapse rate will be decreasing with time.

During the morning and early afternoon we should expect to find increasing lapse rates, and during the remainder of the day we should expect decreasing lapse rates to occur. The effect of the variable diurnal march of temperature at different levels is thus equivalent to a diurnal march of the lapse rate.

II. THE OBSERVATIONAL DATA AND METHOD OF SMOOTHING

A. THE DATA

The data upon which the present study is based were obtained by means of numerous series of kite flights made over a number of years at six aerological stations in the United States. Pertinent facts regarding these stations and the period of years covered will be found in table 1. A series of kite flights consists of a set of flights made as frequently as possible. Kite flights are usually of such length that about seven to nine flights can be made in a 24-hour period.

In making these flights the Marvin-Hargrave kite was used and the free-air data were recorded by the Marvin kite-meteorograph. The procedure employed in making and computing a kite flight is described in **(10)**.

It was intended that two series of flights each continuing over a period of at least 24 hours be made each month. This schedule could not always be carried out, however, due largely to the relatively small number of days when there was sufficient wind over a 24-hour period to fly kites. As a result there was much irregularity as to elapsed time between series, between flights in any one series, and in the heights reached by the individual flights in any given series. Furthermore, the different series were neither started at the same time of day nor did they all continue for a minimum period of 24 hours. These irregularities caused many difficulties in the smoothing of the data.

B. SMOOTHING OF DATA: DIURNAL VARIATION OF TEMPERATURE

In the first step toward smoothing the original data the series were treated as units. For each series the measured temperatures at each of the standard levels up to and including 3,000 m, m.s.l., were plotted against time. A smooth curve was then drawn through each of the sets of points (for each level) and the temperatures at the exact hours read from the curves. Both the ascent and descent records obtained from each individual kite flight were used so that each flight provided two measurements of the temperature at each standard level. Thus, the plotted points were usually never more than 2 hours apart for the levels near the ground. For the higher levels the plotted points were often as far as 3 hours apart (between flights) because at these levels there was less elapsed time between the ascent and descent measurements. It will be evident that this procedure provided hourly temperatures at each standard level for the duration of each series.

Several methods of summarizing similar data have been used in diurnal studies but none appears to be entirely satisfactory. Since the temperatures obtained in the first step did not all cover the same period of hours, the diurnal trend could not be determined from the averages of the hourly temperatures. Any method employing the differences for each hour from some reference hour or from the mean for the day has the especially objectionable feature of being adaptable only with great difficulty to data which do not cover a uniform period. Thus, if one is using the hourly differences from the daily mean, only those observations which cover a 24-hour period can be used. This necessitates discarding much otherwise good data and this is very objectionable when the data are already meager.

The method of smoothing used by Hergesell (2) appears to be quite satisfactory, but necessitates a great amount of work, since the computation involves a least-squares solution of many equations.

The fundamental thing which it is desired to know is how the temperature normally behaves from hour to hour. The method of determining this by averaging *observed temperature changes from hour to hour* at once suggests itself. This is the fundamental principle of the method of smoothing used in this investigation, which was as follows.

When the observed temperatures for any level are plotted as ordinates against time as abscissae and a smooth curve is drawn for each series, each such curve discloses a more or less regular diurnal period. The true nature of this period is not immediately disclosed, however, because combined in the curve as drawn are (*a*) the average annual trend for a calendar day, (*b*) the average trend resulting from the accumulation of systematic errors, and (*c*) the average trend resulting from the accumulation of accidental errors. Therefore, segments of these curves taken for 1 calendar day (24 hours) are not identical. By superimposing a number of such segments obtained from a limited period, such as a season, and then drawing a smooth curve to represent their average trend we obtain a curve which shows the average diurnal trend over the period considered, viz, the season, together with the average annual trend, any systematic errors present, and all accidental errors which have not cancelled out.

The most important causes of the systematic errors just referred to are the limitations inherent in the making of kite observations. Since the wind must be fairly strong, say 8 to 12 miles per hour, before kites can be flown, all kite flights are made in more or less particular conditions. When a series is to be made, the conditions must be of a still more special nature, because in this case the wind must continue to be sufficiently strong for at least 24 hours. It was found by experience that such conditions were usually most likely to occur as a low pressure area was moving toward the station. This meant that usually the temperature in general was rising during a series, which, in fact, is borne out by the nature of the residuals, V, discussed later.

Owing to the effects just considered, the initial and final temperatures of the average diurnal curve obtained are not identical—i.e., the curve is not periodic. The normal curve, however, which it is desired to find, is free from these effects. This normal curve can be approximated by removing the difference between the initial and final temperatures on the average curve by a prorating process.

Let T_i = temperature at the i^{th} hour of the day as would be given by the normal curve for any given season,

$\Delta T_i \equiv T_i - T_{i-1}$ = difference in temperature between the i^{th} and $(i-1)^{th}$ hours on the normal curve,

$d_{ji} \equiv T_{ji} - T_{j(i-1)}$ = observed difference in temperature between the i^{th} and $(i-1)^{th}$ hours on the day j,

and $D_i \equiv \frac{1}{n_i}\sum_{j=1}^{n_i} d_{ji}$ = average observed difference in temperature between the i^{th} and $(i-1)^{th}$ hours for n_i days during the given season, where n_i = number of days during the given season when temperature observations were available for both the i^{th} and $(i-1)^{th}$ hours.

Since ΔT_i is nearly equal to D_i, we may write

$$\epsilon_i \equiv \Delta T_i - D_i \tag{1}$$

where ϵ_i represents a small correction which, when added to the average temperature difference D_i gives the normal temperature difference ΔT_i.

From equation (1) we have

$$\sum_{i=1}^{24} \epsilon_i = \sum_{i=1}^{24} \Delta T_i - \sum_{i=1}^{24} D_i \tag{2}$$

By hypothesis $T_i = T_{(i+24)}$, or $T_{24} - T_0 = 0$. Hence,

$$\sum_{i=1}^{24} \Delta T_i = \sum_{i=1}^{24} T_i - \sum_{i=1}^{24} T_{(i-1)} = T_{24} - T_0 = 0 \tag{3}$$

Substituting equation (3) in (2) we obtain

$$\sum_{i=1}^{24} \epsilon_i = -\sum_{i=1}^{24} D_i \equiv V, \text{ say.} \tag{4}$$

If the number of observations is reasonably large, we may assume that as a close approximation the average value of ϵ_i obtainable from equation 4 may be substituted for the individual hourly values, hence,

$$\epsilon_i = \frac{1}{24} V \equiv -\frac{1}{24} \sum_{i=1}^{24} D_i \text{ (approximately)} \tag{5}$$

or by equation (1)

$$\Delta T_i = D_i + \frac{1}{24} V. \tag{6}$$

In a few cases V was found to be relatively large owing to the accumulation of systematic and accidental errors. In these cases, inspection of the observed differences, d_{ji}, usually disclosed some values which were so large that they were obviously erroneous. These values could then be discarded on the basis of their deviations from the mean value. Otherwise, equations 5 and 6 were considered valid and were used throughout.

The values of ΔT_i, as well as the values of T_i, clearly form a periodic function of time. Therefore, the values of ΔT_i obtained in the manner just described were represented by means of a Fourier series of four terms, the arithmetical values already computed being smoothed in this manner. The equation used in this step may be written,

$$\Delta T_i = f(t) = a_1 \cos \Theta + a_2 \cos 2\Theta + b_1 \sin \Theta + b_2 \sin 2\Theta \tag{7}$$

where $\Theta = \frac{2\pi i}{24}$. In this computation i was considered to be zero (or 24) at 1 a.m., and 23 at midnight.

It will be evident that the constant term a_0, usually required in such a series, is zero in this case because the values of ΔT_i are relative numbers. The constants a_1, a_2, b_1, and b_2 were computed by the method of least squares. New smoothed normal temperature differences were then computed from equation 7 and regarded as the final values. Table 2 shows the values of the constants a_1, a_2, b_1, and b_2 for each level, season, and station.

The reliability of the ΔT_i's obtained as described, depends largely upon the number of observed differences in temperature, which itself differed for the various hours of the day. Ordinarily, a series was begun between 8 a.m. and noon. In most cases the series continued for about 30 hours, so that in a great many instances a series furnished two observations of the temperature difference for these morning hours. In many cases the series was not continued for 24 hours, and so lacked observations for the early morning hours (2 a.m. to 8 a.m.). It was thus found that as a general rule the greatest number of observations occurred at about 11 a.m. and the least at about 6 a.m. Table 3 shows the total number of observations for the four seasons for these two hours arranged according to stations and levels. The number of observations in a single season may be found roughly by dividing the tabular value by 4. The number of series is roughly equal to the number of observations at 6 a.m.

The method of smoothing described above is believed to possess the following important advantages:

(1) Temperature differences are used throughout and the results thus obtained are more reliable than those gotten by the use of actual temperatures.

(2) All data obtained during a series can be used regardless of whether or not they are continuous over a 24-hour period from some reference hour.

(3) A convenient and justifiable basis is provided for discarding data which obviously are either erroneous or so abnormal that they would injure the quality of the entire work. Discarding can be done on the basis of least squares. Any observational value can be rejected without disturbing any other value. The observed differences usually are so small and uniform that any large differences can be immediately detected and investigated.

(4) Small numbers are used throughout, thus reducing the work.

(5) The values of the ΔT form a comparatively smooth curve without further smoothing by graphical means or by means of a series representation.

C. COMPUTATION OF SMOOTHED VALUES FOR THE DIURNAL VARIATION OF LAPSE RATE

The diurnal variation of the lapse rate can easily be computed if the diurnal variation of the temperature is known, as follows:

Let T_i = the normal temperature at any standard level, at hour i,

t_i = the normal temperature at the next higher level, at hour i

L_i = the average lapse rate between the levels at hour i,

$= -\frac{t_i - T_i}{\Delta h}$, where Δh = the difference in altitude of the two levels in hundreds of meters.

$L_i - L_{(i-1)}$ = the change in the lapse rate from the hour $(i-1)$ to the hour i.

Then,

$$L_i - L_{(i-1)} = \frac{-(t_i - t_{(i-1)}) + (T_i - T_{(i-1)})}{\Delta h} \tag{8}$$

Since $(t_i - t_{(i-1)}) \equiv \Delta t_i$ and $(T_i - T_{(i-1)}) \equiv \Delta T_i$, we get

$$L_i - L_{(i-1)} = \frac{\Delta T_i - \Delta t_i}{\Delta h} \tag{9}$$

The smoothed temperature differences computed by means of equation 7 thus can be used in equation 9 for the computation of smoothed hourly lapse-rate changes.

III. COMPARATIVE DISCUSSION OF THE SMOOTHED DATA

A. THE DIURNAL TEMPERATURE TREND

Hourly values of ΔT_i for each level up to 3,000 m, m.s.l., for each season and station were computed by means of equation 7 (sec. II) and accumulated from hour to hour. The accumulated values were plotted against time of day as shown for all seasons and stations in figures 1 to 6, inclusive. The times against which the accumulated values are plotted are those of the meridian in local use.

The curves represent the direction and magnitude of the temperature changes during the day—no actual temperatures being known. Once the normal temperature has been determined for any level at any particular hour, however, the values indicated by the curves (or computed by means of equation 7) are reliable enough to give a close approximation to the normal temperature at any other hour.

The curves that show the diurnal trend at the surface are similar to others previously published, the greatest difference being in the diurnal range. On superimposing the various surface curves given in figures 1 to 6 for any given season, one finds that the range varies considerably and that the maxima and minima at the different stations do not occur at the same standard time but at substantially the same local solar time. All the stations but one, Due West, use 90th meridian time, though they vary considerably in longitude.

Perhaps the outstanding feature of the curves for free-air temperature trend, by comparison with most of the curves heretofore published, is the absence of sufficient visual evidence (the results were not subjected to harmonic analysis), to indicate definitely the existence of any other than the 24-hourly temperature period. Such periods are not plainly indicated by inspection for the levels up to and including 1,500 m, m.s.l., and for levels beyond this no great reliance can be placed in the present values. The greatest difficulty in obtaining reliable values at or above 1,500 m is the fact that at about this height the periodic changes have become so much smaller than the aperiodic that irregularities occur unless the number of observations is very large. For example, the failure of one large aperiodic temperature change to cancel in the data for the 2,000-m level could easily produce a change in the entire appearance of the curve for this level, while with the same number of observations the same error at the surface might produce no noticeable result. In actual practice the greater the height the fewer the observations, and therefore the percentage error in the results for the upper levels is greater for two reasons.

The curves for the standard levels between the surface and 1,500 m, m.s.l., indicate, with only two important exceptions, a very regular diurnal variation of temperature. The magnitude of the period decreases with height and the time of the maxima and minima occur later in the day as the altitude increases (up to certain limits). Evidently, however, curves for any standard height above sea level for different stations are not intercomparable, because the diurnal variation occurs largely with respect to height above ground, and not sea level, and no two of the stations have the same sea-level height.

To compare the displacement of the time of maximum with altitude, the times have been plotted against height above ground for the surface and the standard levels. The results for levels up to 1,500 m, m.s.l., are shown in figure 7. At greater heights there is little or no apparent consistency, the times being spread throughout the day and, seemingly, just as likely to occur at one hour as another when all seasons and stations are considered. This fact appears to deny the existence of a definite diurnal period at these higher levels. It may be, however, (*a*) that a period does exist but is masked by the relatively large errors present, or (*b*) that the diurnal periods at these high levels are actually very different in phase for the various stations, seasons, and levels.

The latter alternative conclusion is possible but does not seem probable.

The two exceptions previously mentioned to a regular diurnal trend of temperature in the lower levels are at Ellendale in winter. Here the winter curves for the 750 and 1,000 m levels indicate a decided tendency toward a secondary maximum between 1 and 3 a.m. The data for these levels were examined carefully for large errors but none was found. The numbers of observations in the various hours were no smaller than for many other curves. Therefore, even though this condition did not appear to be present at the other stations, it seems likely that it is one which actually exists. Since it amounted to only a few tenths of a degree its cause possibly may be dynamical heating due to the sinking of large masses of stable air.

It has been said that a definite 24-hour period exists at 1,000 m, and that the existence of this period at 2,000 m is, in many cases, not clearly indicated by the present data. The 1,500-m level, then, occupies a unique position. We might expect this level to lie either above or below the upper limit of a pronounced diurnal period. But this limit probably changes considerably with season, according as the upper limit of turbulence, the average cloud heights, etc., change with season, and it certainly varies between stations because of their differences in altitude above sea level and the differences in their surrounding topography. Therefore, we should expect to find, as we do, little pronounced regularity in the 1,500-m, m.s.l., curves. In many instances the curve for the 1,500-m level differs from the curves for the levels both above and below, though usually, it is similar to one or the other.

As shown later, there is a region between 1,000 m and 2,000 m above sea level at all the stations under consideration in which the diurnal range is very small and above which the range decreases very slowly with altitude. If any period or periods of diurnal temperature variation exist above this region, they are very small in amplitude, and commonly lost in irregular changes.

In some cases it is necessary to know actual temperatures. To this end, the temperatures read at the morning observations at the six stations over a number of years were averaged, and the values thus found listed in table 4. The average time of the readings was about 6:45 a.m., local time, for all the stations except Due West where it was about 7:45 a.m.

The average lapse rate at 11 a.m. was found for each station, season, and level interval from the data furnished by the series flights; these are shown in table 5. The hour 11 a.m. was chosen because (*a*) the greatest number of observations occurred at about this time, and (*b*) the observed lapse rates were more nearly uniform at this hour than either earlier or later.

Approximate average temperatures can be found for all hours of the day at all levels by means of tables 4 and 5 and equation 7.

B. THE DIURNAL TEMPERATURE RANGE

The diurnal range for each station, season, and level was computed from the absolute maximum and minimum for the day.

To facilitate the study of the variation of range with season, the ranges for the various levels were plotted against altitude and smooth curves drawn through the points. Figures 8 to 13, inclusive, show these curves for all seasons grouped according to station.

To compare the ranges at different stations for any level we must know their ranges at the same height above ground. To this end the heights of the various standard levels above ground were computed for each station and the ranges for the various levels plotted against these heights. Smooth curves were drawn through the points. Figures 14a to 14d show these curves for all stations grouped by seasons.

Figures 8 to 13 show that at the surface, with one exception, the diurnal range was greater in spring than in summer at all stations for which data for the two seasons were available. The exception occurred at Royal Center, where little difference was found in the ranges for the two seasons. The greatest difference between the ranges for the two seasons was found at Ellendale and amounted to about 0.6° C. No such regularity was found, however, for the other seasons. In autumn, the ranges at Ellendale and Royal Center were less than those for spring and summer but greater than those for winter. At the remaining stations the range was greater in autumn than in any other season. The smallest range occurred in winter at Ellendale, Drexel, Royal Center, and Due West, while at Broken Arrow the range in winter was less than in autumn but greater than in spring and summer.

The present discussion of the results of this investigation is not intended to be explanatory, but it might be mentioned that the albedo and evaporation of the surface snow cover, the relatively small number of hours of sunshine, and the low average temperature are all probably quite instrumental in decreasing the diurnal ranges at Ellendale, Drexel, and Royal Center in winter to a value lower than that for the other stations.

At levels from a few meters above the surface to 700 to 1,200 m above the surface, the diurnal ranges at all stations show a regular seasonal march. At these levels for two of the stations, viz, Royal Center and Drexel, the range is greater in summer than in spring; at Groesbeck and Broken Arrow it is greater in spring than in summer; and at Ellendale the ranges for these two seasons are nearly equal at most levels. The winter curves for Royal Center and Ellendale are apparent exceptions to this rule at levels greater than about 500 and 600 m above ground, respectively. At and above these levels at these stations in winter the rate of decrease of range with altitude is very small, and the range is greater than in the other seasons.

At levels higher than those just considered the diurnal range remains nearly constant with increasing altitude, insofar as can be determined from the present data, and there is little apparent regularity of variation in the range with respect to season.

Figures 14a to 14d show an especially outstanding feature—the position of the curves for Groesbeck for the respective seasons. In all seasons at Groesbeck the ranges in the intermediate levels are greater than at any other station considered. This difference is most marked in spring and summer, the latter season not being represented for Due West. In autumn the ranges for Groesbeck and Due West are nearly equal at these levels, but both are decidedly greater than for any other station. In winter there is the least difference in the ranges, but the range at Groesbeck is still the largest. This outstandingly large range is neither shown for the surface nor above levels varying from about 900 m above ground in winter to about 1,600 m above ground in spring.

There are two exceptions to the statements just made. Notably, the range at Due West is greater than that at Groesbeck at altitudes above, roughly, 700 m above ground in autumn and 1,100 m in spring. It is to be regretted that data for summer for Due West are not available.

The relatively large ranges at Due West and Groesbeck are probably brought about mainly by the relatively great amounts of water vapor at these two stations.

There appears to be a tendency in the lower levels for the range to increase as one proceeds southward during all seasons. Conditions at Ellendale, where the range is, for most seasons, greater than we should expect from the geographical position of the station, seem to depart most widely from this general rule.

C. THE DIURNAL VARIATION OF LAPSE RATE

The normal changes in lapse rate from hour to hour were computed by means of equation 9. The differences were then accumulated in a manner similar to that employed in accumulating the temperature differences and the accumulated values plotted against time of day. The curves are not shown herewith, but the change of lapse rate can be traced graphically by noting the variation of the distance between the curves in figures 1 to 6. The distances themselves are not proportional to the actual lapse, but the changes in distance between any two curves are proportional to the changes in the average lapse rate between the respective levels.

Approximate hourly average lapse rates between the various levels can be found by means of table 5 and equation 9.

The manner in which the lapse-rate changes during the day due to the change of the diurnal range with altitude is of interest, since an inversion during part of the day is a necessary consequence if the decrease of range with altitude is great enough, or if there is a large change of phase with altitude. Thus, near the surface where the decrease of temperature range with altitude is comparatively great, the lapse-rate range is also large and an inversion must occur during the night unless very large lapse-rates exist during the day.

As a general rule, inversions exist at all stations and all seasons near the surface during the night hours, and superadiabatic lapse rates during some hours of the afternoon except for the winter season at northern stations.

IV. EVALUATION OF COEFFICIENTS RELATING TEMPERATURE CHANGES TO RADIATION AND TURBULENCE

As stated above, according to Brunt the time rate of change of temperature due to radiation between superposed air layers is given approximately by the expression $K_r\frac{\delta^2 T}{\delta Z^2}$ and that due to turbulence is given approximately by $K\frac{\delta^2 T}{\delta Z^2}$. Brunt then concludes that the combined effects of radiation and turbulence are given roughly by

$$\frac{\delta T}{\delta t}=(K+K_r)\frac{\delta^2 T}{\delta Z^2} \tag{1}$$

The value of K can be shown to be so much larger than that of K_r that $(K+K_r)$ may be roughly considered as representing K alone when its value is much larger than the largest limit of K_r (about 10^3), (Brunt (5)). This usually is true when there is even a small amount of turbulence. If $(K+K_r)$ could be evaluated, then, we could gain a valuable insight into the degree and extent of turbulence.

$(K+K_r)$ could evidently be evaluated for all times of the day if the distribution of the temperature were known in sufficient detail; that is, if the hourly temperatures were known at all elevations. It does not appear, however, that the term $\frac{\delta T}{\delta t}$ in equation 1 takes into account heating or cooling from any source other than radiation between layers and turbulence, while any observed $\frac{\delta T}{\delta t}$ depends upon the heating or cooling from all sources. Therefore, if $(K+K_r)$ is evaluated for the daylight hours from temperature data, one must assume either that the temperature change caused by all factors other than reradiation and turbulence is negligible or that the values obtained for $(K+K_r)$ are unreliable to a certain degree.

An attempt was made to evaluate this quantity at various times of the day, at different levels, and for different seasons from the data at hand. It was found, however, that the values obtained varied over a wide range, and that many large negative values were obtained. These negative values usually were found at times near the minimum or maximum and at higher levels where either $\frac{\delta T}{\delta t}$ or $\frac{\delta^2 T}{\delta Z^2}$ or both were relatively small. It is most probable that the discrepancies found were caused by errors in the lapse rates used. This seems likely when it is considered that an error of ± 0.05 in each of the lapse rates in two successive air layers may change the sign of $(K+K_r)$ at the times and levels just mentioned. Since the errors in the lapse rates used can easily be much larger than this, it is useless to attempt to get any values for $(K+K_r)$ at times or for levels where such errors in the lapse rates could produce such relatively large errors in the result. The investigation was therefore limited to conditions in which $\frac{\delta^2 T}{\delta Z^2}$ had a relatively large numerical value, either positive or negative; that is, it was limited to times well removed from the maximum or minimum and to the first or second standard levels nearest the ground.

In view of the foregoing, equation 1 was used to compute values of $(K+K_r)$ only for the 750 m, m.s.l., level for all seasons for various hours of the day at Drexel, Nebr. The results are shown in table 6. These values are seen to be ten to a hundred times as large as K_r, which alone should not exceed about 10^3, hence they indicate considerable turbulence.

$(K+K_r)$ was much larger during the middle of the day than during the night, indicating more turbulence during the daytime.

However, the values during the hours of sunshine are probably too large, so that the degree of turbulence probably is somewhat less than is indicated by the values of $(K+K_r)$ shown. The values during these two periods of the day (daytime and night) are roughly constant, within the range of accuracy of the observations, in each period.

$(K+K_r)$ is largest, as would be expected, in summer. The smallest values appear to have a tendency to occur in winter, but here again, even at the 750 m level, due to the steep winter inversion, relatively large errors are likely to occur because of the relatively small value of $\frac{\delta^2 T}{\delta Z^2}$. At this level in winter we should expect to find little turbulence, so that K_r is probably of the same order of magnitude as K.

G. I. Taylor (6) has given a solution of equation 1 and has shown how the value of the coefficient may be computed from the diurnal temperature ranges at two different altitudes. The value of $(K+K_r)$ obtained by using this solution is strictly valid only if the temperature varies in a manner similar to the sine function. This is approximately true of the temperature variation near the surface. According to this solution

$$b^2 = \frac{\Pi}{T(K+K_r)}, \text{ where} \qquad (2)$$

$$b = \frac{\log_e R_1 - \log_e R_2}{\Delta Z} \qquad (3)$$

T is the periodic time (1 day = 86,400 sec.); R_1 and R_2 are the diurnal ranges at levels 1 and 2, respectively, which differ in altitude by ΔZ centimeters.

Taking $Z = 20{,}000$ cm and solving for $(K+K_r)$, we get

$$(K+K_r) = \frac{27.43 \times 10^2}{\left(\log_{10}\frac{R_1}{R_2}\right)^2} \qquad (4)$$

In order to get some idea of the degree of turbulence at different stations, equation 4 was used to compute $(K+K_r)$ for successive 200-m intervals above the surface for the various seasons at four stations. The magnitudes of the ranges at the different heights were read from curves plotted as shown in figure 14. The values of $(K+K_r)$ thus obtained are shown in table 7.

These values show a wide variation with season and station. Some variation is to be expected because of the differences in the mean wind velocity and direction and surface characteristics at the different stations. In a general way, however, the values of $(K+K_r)$ appear to be consistent with many known temperature tendencies. For the present considerations it is permissible to regard the values as representative of K alone.

At Ellendale in all seasons $(K+K_r)$ was found to be much smaller near the surface than at altitudes a little higher. This is to be expected, since, owing to the large surface inversions at this station we should expect to find little turbulence near the ground. Near the level of about 400 m above ground, however, the steepest part, if not all, of the inversion has been passed, especially in the seasons other than winter, and we find that the values of $(K+K_r)$ indicate considerable turbulence above this level. Between the surface and 200 m little turbulence is indicated, which is probably true, since an inversion exists most of the day in this region in winter.

At Drexel and Broken Arrow the values of $(K+K_r)$ average smaller and vary less with height than at Ellendale, and are roughly of the same magnitude at both stations. This is an indication of less turbulence, on the average, at the former two stations than at the latter. The values at Drexel for the layers near the surface for all seasons except summer appear to be comparatively small, an indication of the surface inversion.

The values for Groesbeck for spring and summer are consistently larger than those for the other stations for any season. Observations show that there is a very frequent inversion at Groesbeck in summer in the neighborhood of 600 m or 800 m above ground. This fact is indicated by the present data in the sharp decrease of $(K+K_r)$ for this season and station in the 600–800 m level, which

indicates that there is a decided decrease in the degree of turbulence above the 600-m level. At this station again, the value of $(K+K_r)$ is decidedly smaller in winter near the surface.

Comparatively large errors are expected to be present in the values of $(K+K_r)$ derived as described above, the main sources of which are believed to be

(1) Inapplicability of the method of computation to the data, owing to, (*a*) inconstancy of $(K+K_r)$ with altitude and (*b*) material deviation of many of the temperature curves from the simple sine curve.

(2) Disregard of that part of the heating or cooling which might have been produced by direct absorption of solar energy, formation and evaporation of clouds, and other factors operating.

V. SUMMARY

The principal factors operating to produce temperature changes at the surface and in the free air have been introduced and a brief explanation given of their mode of operation. The factors discussed are (1) solar radiation, (2) reradiation between the ground, clouds, and atmosphere, (3) vertical convection, (4) changes of phase of water, (5) advection, (6) conduction.

A qualitative discussion of the magnitude of the diurnal range to be expected under various conditions is given under the headings (1) water vapor, (2) nature of surface, (3) mean air displacement, (4) number of hours of sunshine, (5) miscellaneous.

A diurnal variation in the lapse rate is shown to be a necessary consequence of differential changes of temperature with altitude.

Because of its large relative importance in a study such as this in which there is a very limited amount of data, the method of smoothing has been treated in some detail.

Various tables and figures are introduced showing the trend and magnitude of the diurnal temperature change; the variation of the time of diurnal maximum and minimum with altitude; the variation of the magnitude of the diurnal range with altitude; and the variation of the latter with season and station. Tables also are given showing various values of $(K+K_r)$, where $(K+K_r)$ is defined by equation 1 (sec. IV).

These figures and tables are discussed qualitatively and in a general way rather than in very great detail because this is a preliminary study only. It is necessary to know the magnitudes of several factors before any attempt is made to explain many of the characteristics of the temperature curves and even before too much emphasis is laid upon the actual existence of these characteristics. Similar studies of the diurnal variation of relative humidity, vapor pressure, and wind, based on this same set of material, will be made in the future. It is to be expected that relationships will be found between many of the various factors.

At present, however, it appears to be justifiable to draw the following conclusions:

(1) A definite single period of diurnal temperature variation exists up to an altitude roughly in the neighborhood of 1,000 m above ground.

(*a*) The magnitude of the diurnal range decreases rapidly with height immediately above the ground and then somewhat less rapidly up to this level.

(*b*) Beyond this level the magnitude of the diurnal range is, in general, less than 1° Centigrade.

(*c*) Above this level, if a definite diurnal period exists, the amplitude is quite small.

(2) In view of the number of observations upon which they are based and the size of the aperiodic changes present, the data at hand cannot be expected to indicate clearly in all cases the true diurnal period at levels higher than about 1,200 m above ground.

(3) The times of diurnal maximum and minimum occur later in the day with increasing altitude for some distance above the surface. At heights greater than about 800 m above ground, however, the rate of lag of time of maximum or minimum with altitude in many cases becomes irregular, and at heights greater than about 1,000 m above ground there is little apparent consistency in these times.

(4) The lapse rate has a regular diurnal period over the range in altitude in which a definite temperature period exists.

(5) More observations are necessary for the higher levels where the periodic changes are relatively small, than are necessary for the levels near the ground to obtain the same degree of accuracy in the final results.

(6) No immediate conclusions can be drawn regarding the change of the diurnal temperature march with latitude or longitude because certain other factors which cannot at present be evaluated appear to produce effects of the same order of magnitude as those of geographic position.

(7) A graph showing range plotted against altitude is not as good a criterion, in general, for the existence of a definite period as one showing time of maximum or minimum plotted against altitude. The latter, however, does not present proof.

Special acknowledgment is due Mr. C. J. Doering and Mr. C. Russo of this division for their assistance throughout the investigation and to Mr. L. P. Harrison, also of this division, whose valuable suggestions and criticisms aided in the writing of this paper.

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TABLE 1.—*Stations at which series were made*

Station	Altitude, m.s.l.	Latitude north		Longitude west		Meridian time used	Period covered by series
		°	′	°	′		
Ellendale, N.Dak	444	45	59	98	34	90th	1918–25
Drexel, Nebr	396	41	20	96	16	...do	1916–25
Broken Arrow, Okla	233	36	02	95	49	...do	1920–24
Groesbeck, Tex	141	31	30	96	28	...do	1918–25
Royal Center, Ind	225	40	53	86	29	...do	1918–25
Due West, S.C	217	34	21	82	22	75th	1921–29

TABLE 2.—*Fourier Series Constants*

Station	Level, m., m.s.l.	Spring A1	Spring A2	Spring B1	Spring B2	Summer A1	Summer A2	Summer B1	Summer B2	Autumn A1	Autumn A2	Autumn B1	Autumn B2	Winter A1	Winter A2	Winter B1	Winter B2
Ellendale, N.Dak.	Surface (444)	−1.09	0.27	1.20	−0.33	−0.98	0.19	1.23	−0.16	−0.78	0.46	1.00	−0.60	−0.68	0.54	0.63	−0.47
	750	−.58	.11	.07	−.18	−.50	.24	.39	−.03	−.48	.25	.17	−.04	−.11	.26	.06	−.12
	1,000	−.41	.07	−.06	−.03	−.41	.17	.18	−.05	−.18	.09	−.06	.04	−.07	.21	−.13	−.10
	1,500	−.19	−.03	−.10	.01	−.15	.04	.03	.03	−.03	.00	.05	.00	−.14	.14	−.05	−.15
	2,000	−.11	−.03	−.06	.05	−.02	−.07	−.01	.07	.00	.06	.06	−.08	−.10	.12	.07	.07
	2,500	−.07	−.02	−.02	.04	−.08	−.10	−.04	.00	.01	.03	.04	−.09	−.11	.10	−.05	.08
	3,000	.00	−.01	.00	.02	−.11	−.07	.03	−.03	−.01	.06	.07	−.06	−.15	.01	.10	.04
Drexel, Nebr.	Surface (396)	−.98	.37	.97	−.30	−.94	.26	.98	−.31	−.96	.44	1.01	−.69	−.81	.58	.55	−.41
	750	−.41	.27	.07	−.03	−.57	.21	.06	−.01	−.37	.15	.00	.01	−.27	.15	−.06	−.08
	1,000	−.15	.15	.05	−.03	−.29	.12	−.08	.12	−.17	.08	−.03	.00	−.10	.10	−.03	−.08
	1,500	.01	.07	−.03	−.01	−.09	−.01	−.06	.01	−.08	.03	.05	−.05	−.08	.03	.02	−.03
	2,000	.00	−.08	.04	.00	−.09	−.01	.01	−.04	−.08	.04	−.01	−.08	−.06	.03	.12	−.04
	2,500	−.02	−.03	.03	−.05	−.07	.00	.02	.01	−.13	.05	.04	−.07	−.08	.05	.11	−.05
	3,000	.02	.00	.05	−.06	−.07	.02	.02	.08	−.07	−.06	.02	−.06	−.04	−.02	.12	−.02
Broken Arrow, Okla.	Surface (233)	−.82	.22	.96	−.28	−.80	.22	.97	−.32	−.75	.37	1.05	−.65	−.89	.60	.84	−.60
	500	−.67	.20	.36	−.13	−.59	.21	.35	−.14	−.45	.14	.28	−.28	−.50	.26	.26	−.13
	750	−.47	.24	.12	.05	−.39	.22	.05	.00	−.32	.12	.05	−.03	−.19	.04	.03	.06
	1,000	−.24	.19	.03	.09	−.23	.13	.03	.05	−.17	.00	.02	−.07	−.03	.01	.04	.12
	1,500	−.06	.10	.01	.04	−.03	.05	−.04	.05	.01	.00	.00	−.02	.06	.03	.10	.06
	2,000	−.10	−.03	.03	.06	.01	.04	−.07	.01	.08	.00	−.03	.12	.00	−.02	.03	.01
	2,500	.06	.00	.07	.15	.01	−.03	−.05	.04	−.02	.03	−.08	.03	.02	−.10	.04	−.02
	3,000					−.02	.06	−.02	.00	−.02	−.01	−.08	.08				
Groesbeck, Tex.	Surface (141)	−.99	.37	.84	−.16	−.89	.17	.91	−.16	−.94	.25	.98	−.57	−.98	.44	.80	−.44
	500	−.79	.30	.40	.15	−.78	.24	.19	.00	−.59	.32	.34	.07	−.43	.18	.07	.15
	750	−.61	.32	.17	.14	−.59	.29	.22	.04	−.42	.24	.20	.08	−.39	.05	.01	.09
	1,000	−.32	.41	−.01	.10	−.36	.30	.08	.03	−.29	.18	.03	.00	−.19	−.02	−.11	−.03
	1,500	−.04	.15	−.14	−.06	−.11	.10	−.05	.07	−.08	.01	−.01	−.06	.06	.02	−.09	−.04
	2,000	.03	−.01	.10	−.04	−.02	−.08	.05	.08	−.01	.03	.01	.03	−.07	.07	−.09	.02
	2,500	−.04	.02	.03	.01	.09	−.04	−.06	−.07	.02	.01	.04	.05	−.09	.07	−.08	.09
	3,000	−.04	.01	.05	.06	.06	−.06	.02	.03	.03	.09	−.03	.09	−.02	.06	.00	−.08
Royal Center, Ind.	Surface (225)	−.75	[illegible]	1.14	.49	−.65	−.04	1.26	.30	−.60	.12	1.02	−.72	−.49	.49	.31	−.56
	500	−.51	.21	.31	.21	−.55	.15	.58	.30	−.32	.23	.28	−.27	−.34	.34	.12	−.17
	750	−.31	.06	.13	.03	−.33	.12	.26	.09	−.19	.17	.12	−.12	−.29	.29	.08	−.05
	1,000	−.17	.09	.09	.00	−.26	.18	.06	.12	−.13	.10	.04	−.04	−.20	.20	.06	.07
	1,500	−.03	.08	.08	.09	−.06	.02	.11	.01	.00	.14	−.03	.01	−.10	.19	.06	−.02
	2,000	.01	.05	.01	.16	−.07	−.09	.05	.07	.03	.15	−.01	.00	−.07	.18	.07	−.04
	2,500	−.03	−.01	.02	.01	−.05	−.05	.03	.06	.09	.10	.05	.03	−.09	.20	.09	.01
	3,000	.07	−.08	.02	−.09	−.11	−.05	.02	.08	−.03	.11	.11	.06				
Due West, S.C.	Surface (217)	−.84	.14	.68	−.32					−.88	.27	.88	−.54	−.71	.43	.67	−.40
	500	−.65	.27	.30	−.08					−.60	.30	.33	−.14	−.44	.26	.33	−.10
	750	−.50	.18	.15	.08					−.48	.20	.16	.01	−.32	.14	.14	.03
	1,000	−.38	.16	.15	.02					−.38	.06	.09	.06	−.20	.08	.07	.02
	1,500	−.14	.04	.25	.10					−.17	−.14	.09	.08	−.04	.00	.02	.04
	2,000	−.05	.08	.22	.11					−.08	.03	.10	.08	.06	.13	−.01	−.09
	2,500	.01	.13	.12	.00					−.11	.01	.05	.00	.01	.07	−.07	.15
	3,000									−.10	.04	.01	.10				

TABLE 3.—*Total number of observations for the 4 seasons*

Level, m., m.s.l.	Ellendale, N.Dak. 6 a.m.	Ellendale, N.Dak. 11 a.m.	Drexel, Nebr. 6 a.m.	Drexel, Nebr. 11 a.m.	Broken Arrow, Okla. 6 a.m.	Broken Arrow, Okla. 11 a.m.	Groesbeck, Tex. 6 a.m.	Groesbeck, Tex. 11 a.m.	Royal Center, Ind. 6 a.m.	Royal Center, Ind. 11 a.m.	Due West, S.C. 6 a.m.	Due West, S.C. 11 a.m.
Surface	58	116	116	204	50	91	48	88	59	109	[1] 35	[1] 58
500					50	91	47	88	57	109	[1] 35	[1] 58
750	58	114	112	201	50	90	48	88	55	108	[1] 34	[1] 55
1,000	55	108	108	193	50	89	48	85	49	108	[1] 32	[1] 53
1,500	50	106	109	192	47	86	46	81	42	104	[1] 28	[1] 48
2,000	43	106	106	188	43	82	45	76	38	96	[1] 23	[1] 45
2,500	30	83	97	173	28	62	37	66	27	71	[1] 14	[1] 34
3,000	22	57	82	150	[1] 16	[1] 33	20	41	13	30	[2] 5	[2] 9

[1] 3 seasons only. [2] 2 seasons only.

TABLE 4.—*Mean temperature at the morning observation*

Station	Spring	Summer	Autumn	Winter	Period averaged
	° C.	*° C.*	*° C.*	*° C.*	
Ellendale, N.Dak.	1.1	15.2	2.3	−12.5	13 years.
Drexel, Nebr.	5.4	19.1	6.8	−7.6	10 years.
Broken Arrow, Okla.	10.8	22.0	11.5	.4	12 years.
Groesbeck, Tex.	14.6	23.4	15.2	6.0	Do.
Royal Center, Ind.	6.6	19.1	8.5	−4.5	Do.
Due West, S.C.	12.8	22.7	13.6	3.8	10 years.

TABLE 5.—*Average lapse rates at 11 a.m.*

Level interval (levels in m., m.s.l.)	Ellendale, N.Dak. Spring	Ellendale Summer	Ellendale Autumn	Ellendale Winter	Drexel, Nebr. Spring	Drexel Summer	Drexel Autumn	Drexel Winter	Broken Arrow, Okla. Spring	Broken Arrow Summer	Broken Arrow Autumn	Broken Arrow Winter	Groesbeck, Tex. Spring	Groesbeck Summer	Groesbeck Autumn	Groesbeck Winter	Royal Center, Ind. Spring	Royal Center Summer	Royal Center Autumn	Royal Center Winter	Due West, S.C. Spring	Due West Summer	Due West Autumn	Due West Winter
Surface—500									1.17	1.36	1.18	0.55	1.17	1.31	1.16	0.97	1.31	1.46	1.29	0.75	1.18		1.38	0.86
Surface—750	1.06	1.20	0.77	−0.33	1.04	1.20	0.81	−0.11																
500-750									.91	.98	.86	.29	.81	.95	.78	.34	.94	1.02	.82	.15	.86		.92	.54
750-1,000	.76	.81	.28	−.38	.48	.69	.24	−.26	.65	.71	.50	.01	.68	.78	.47	.10	.56	.90	.45	.06	.69		.62	.44
1,000-1,500	.71	.53	.25	.06	.38	.47	.31	.08	.53	.68	.39	.12	.29	.48	.46	.14	.52	.61	.34	.13	.57		.39	.40
1,500-2,000	.61	.66	.42	.34	.49	.70	.51	.31	.50	.66	.36	.43	.33	.39	.38	.36	.43	.58	.47	.34	.50		.28	.30
2,000-2,500	.58	.61	.48	.52	.61	.73	.59	.49	.57	.59	.44	.52	.49	.57	.48	.46	.50	.56	.49	.39	.57		.42	.40
2,500-3,000	.63	.55	.60	.51	.67	.80	.56	.47		.60	.43		.58	.54	.48	.45	.52	.58	.45				.51	

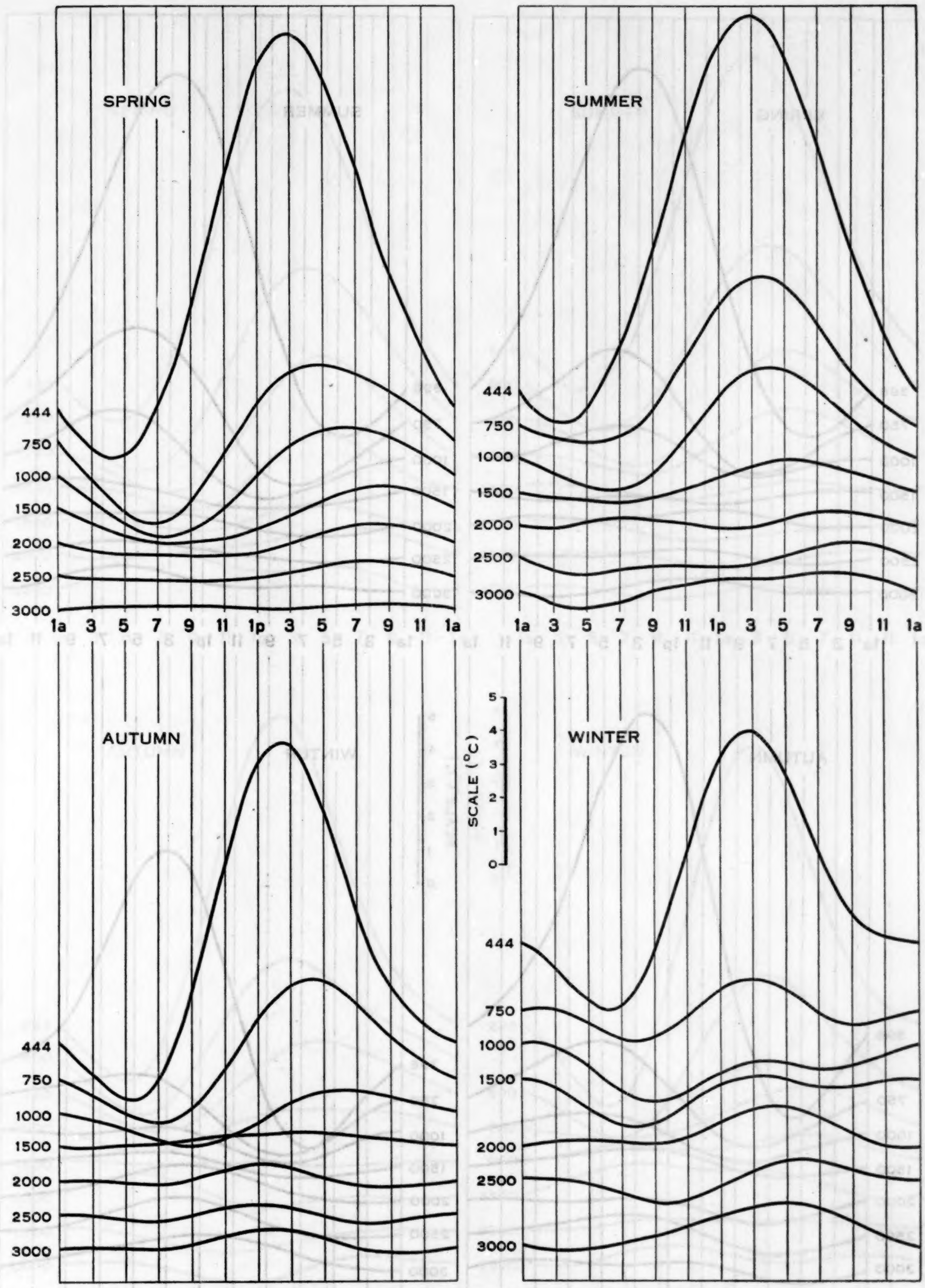

FIGURE 1.—Diurnal temperature march at Ellendale, N.Dak., at indicated altitudes in m, m.s.l.

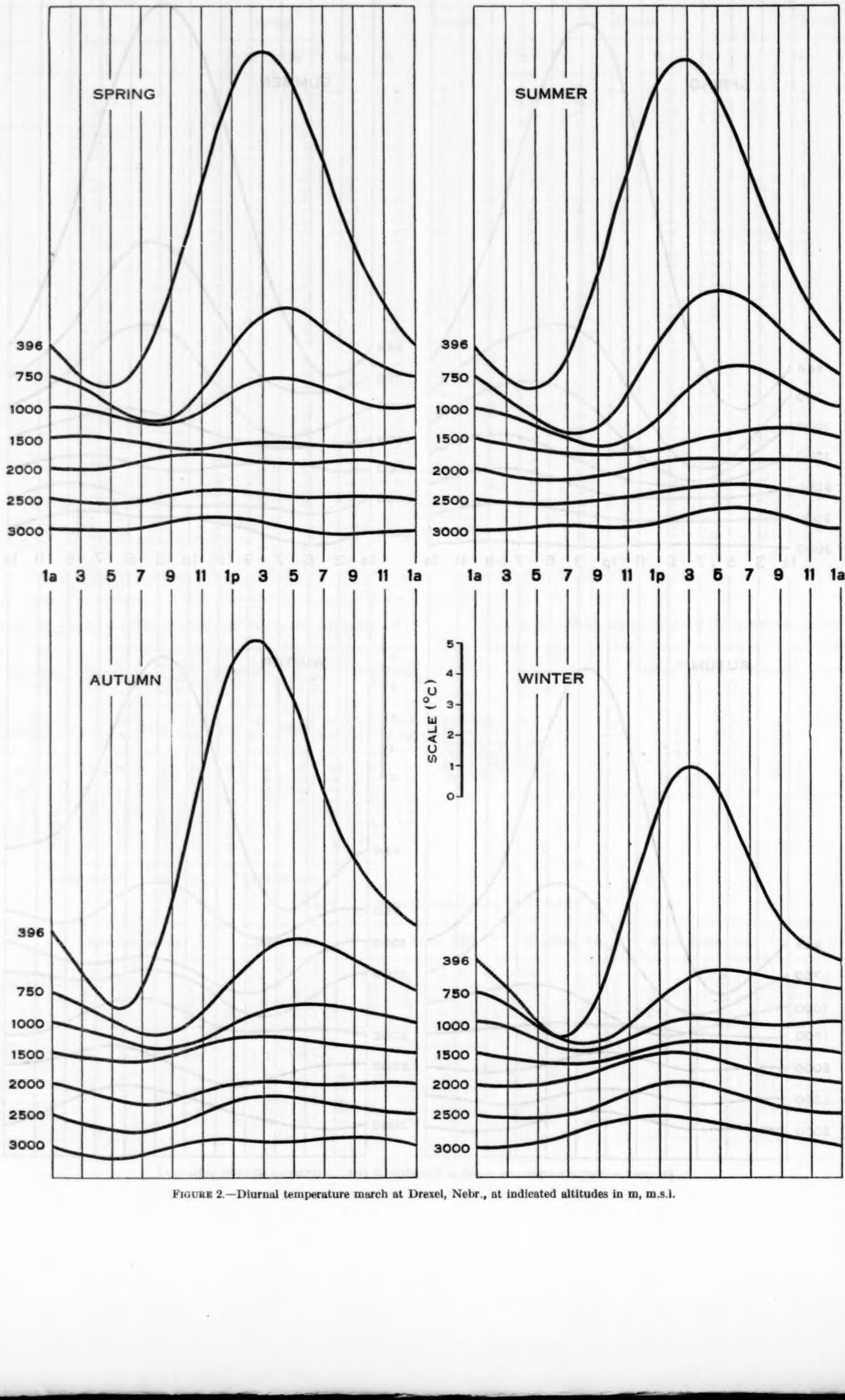

FIGURE 2.—Diurnal temperature march at Drexel, Nebr., at indicated altitudes in m, m.s.l.

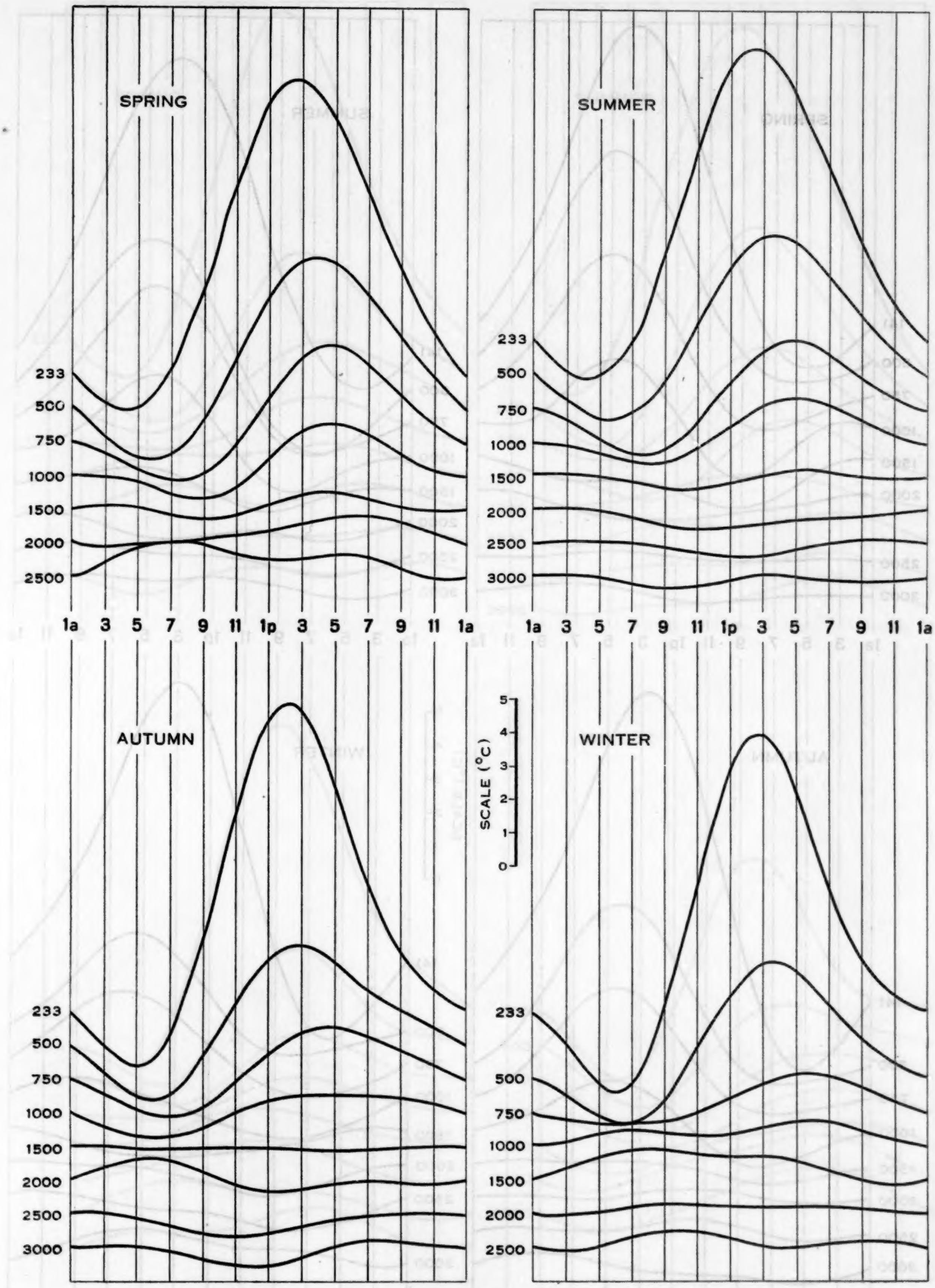

FIGURE 3.—Diurnal temperature march at Broken Arrow, Okla., at indicated altitudes in m, m.s.l.

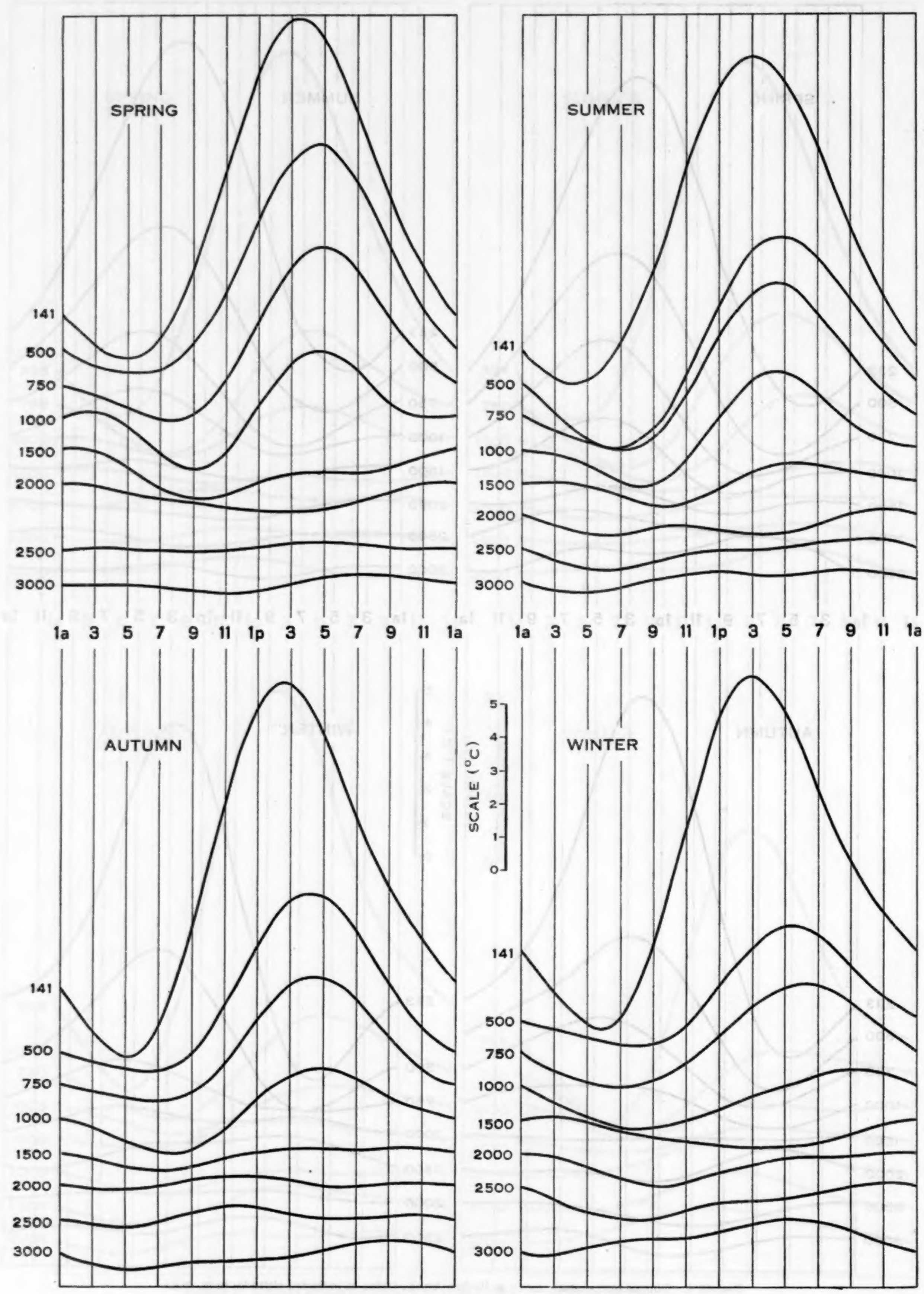

FIGURE 4.—Diurnal temperature march at Groesbeck, Tex., at indicated altitudes in m, m.s.l.

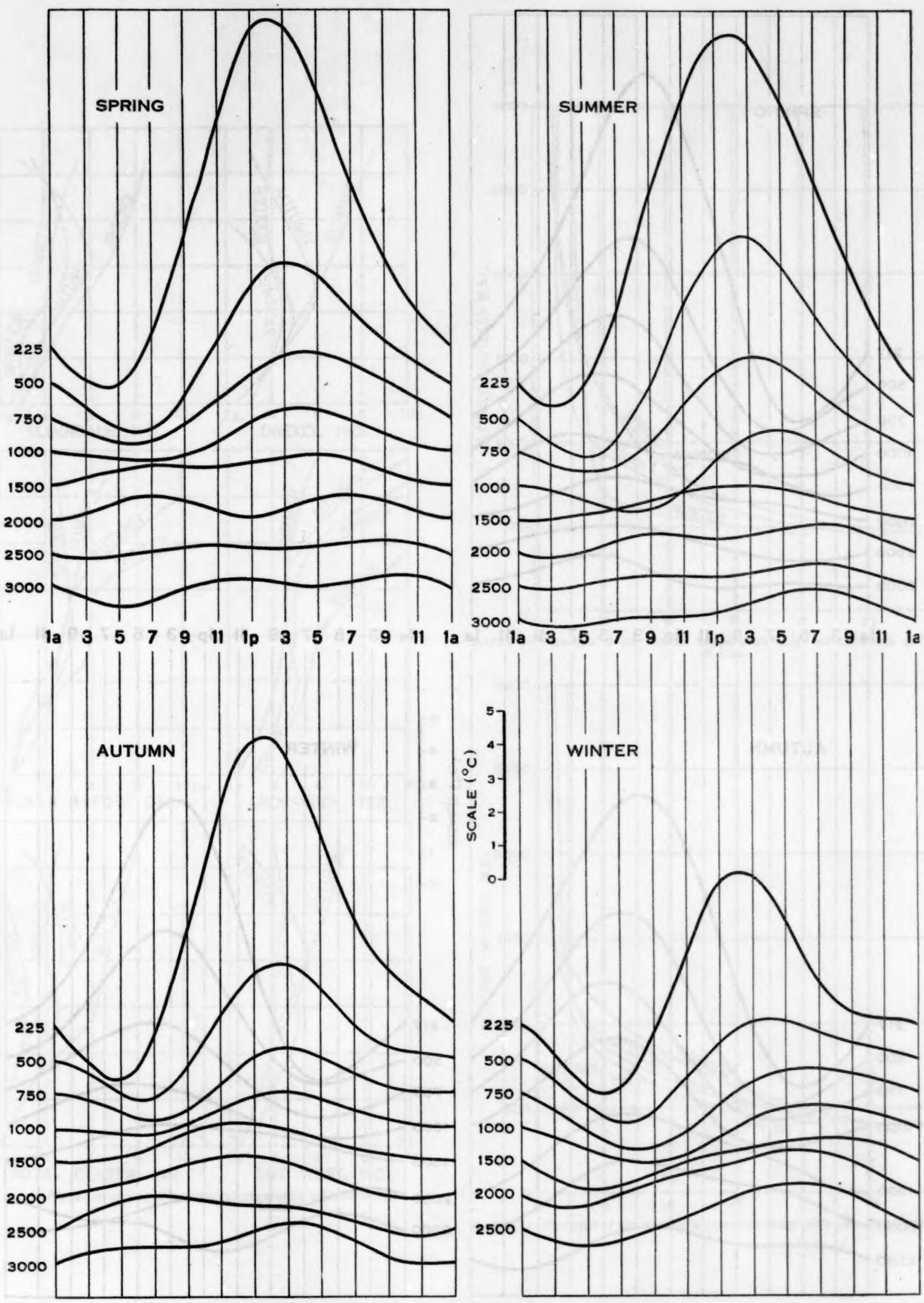

FIGURE 5.—Diurnal temperature march at Royal Center, Ind., at indicated altitudes in m, m.s.l.

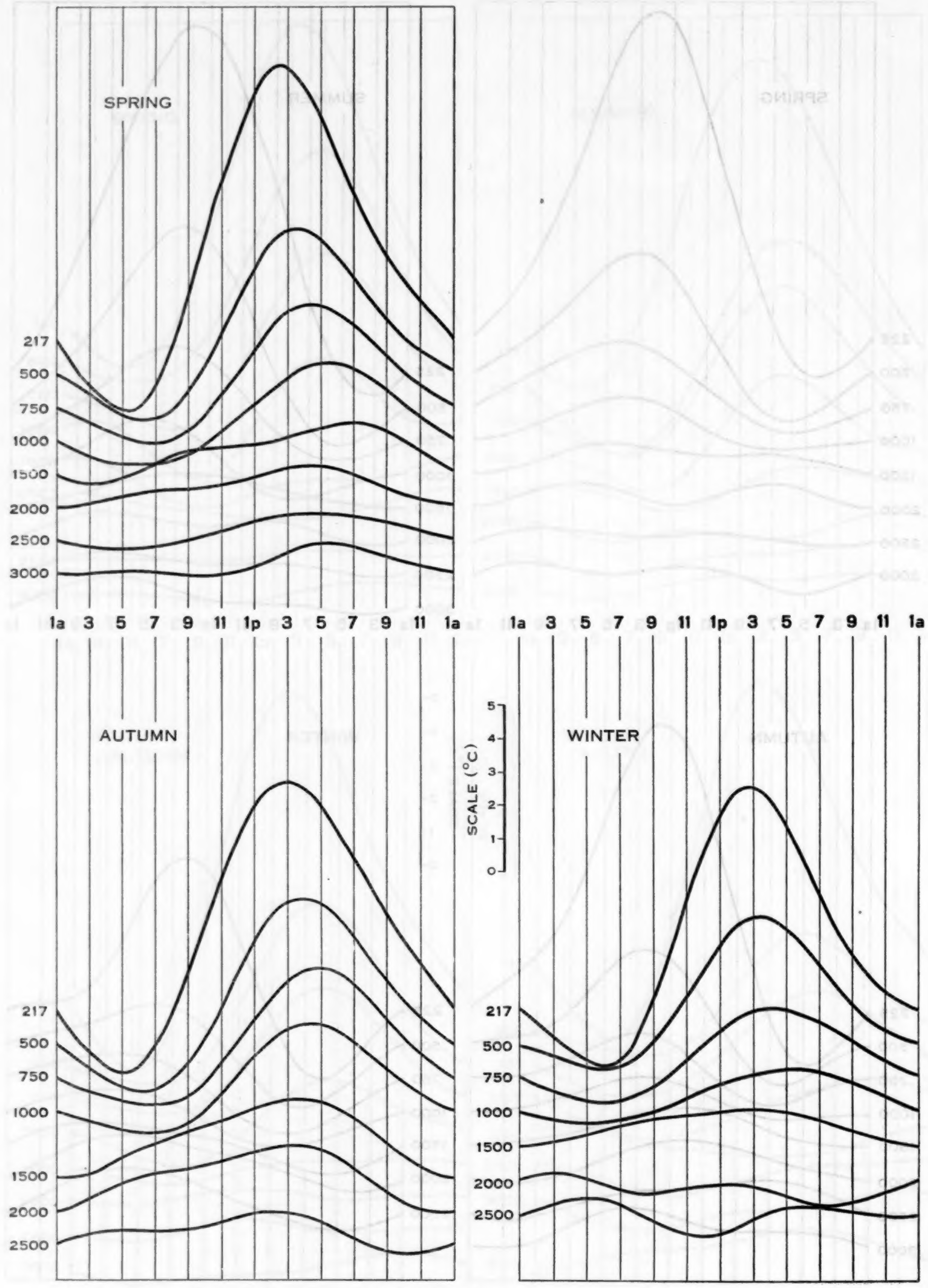

FIGURE 6.—Diurnal temperature march at Due West, S.C., at indicated altitudes in m, m.s.l.

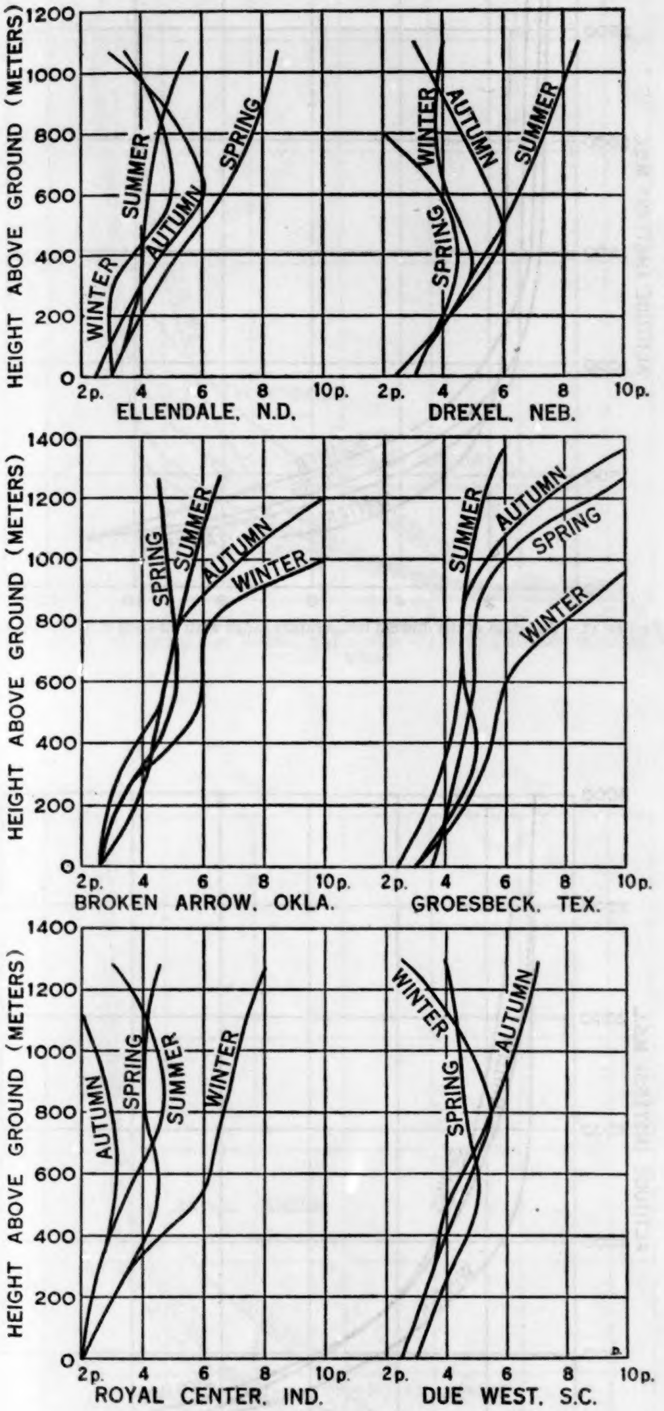

FIGURE 7.—Variation of time of maximum temperature with altitude.

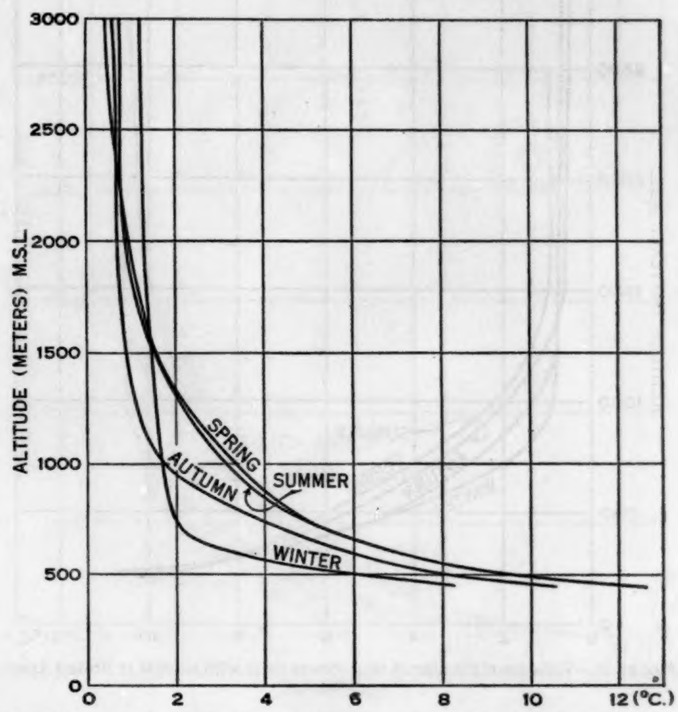

FIGURE 8.—Variation of the diurnal temperature range with altitude at Ellendale, N.Dak.

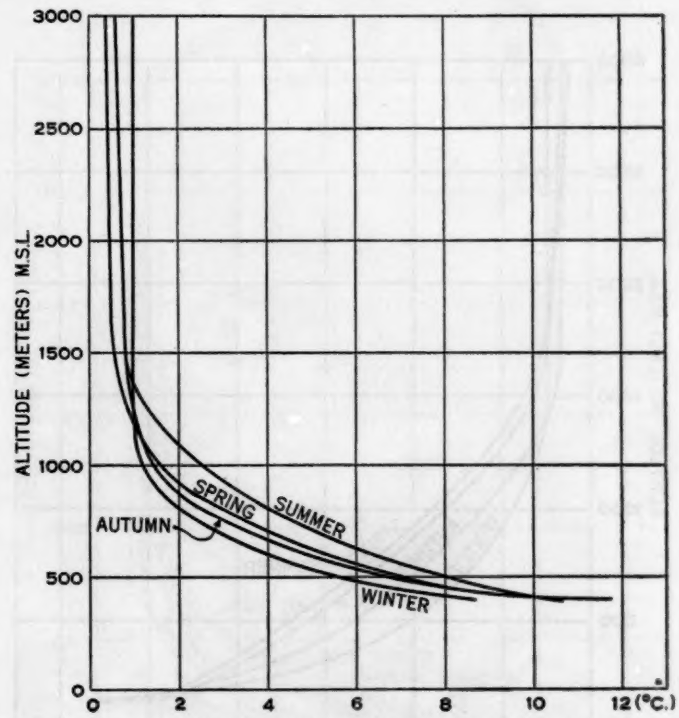

FIGURE 9.—Variation of the diurnal temperature range with altitude at Drexel, Nebr.

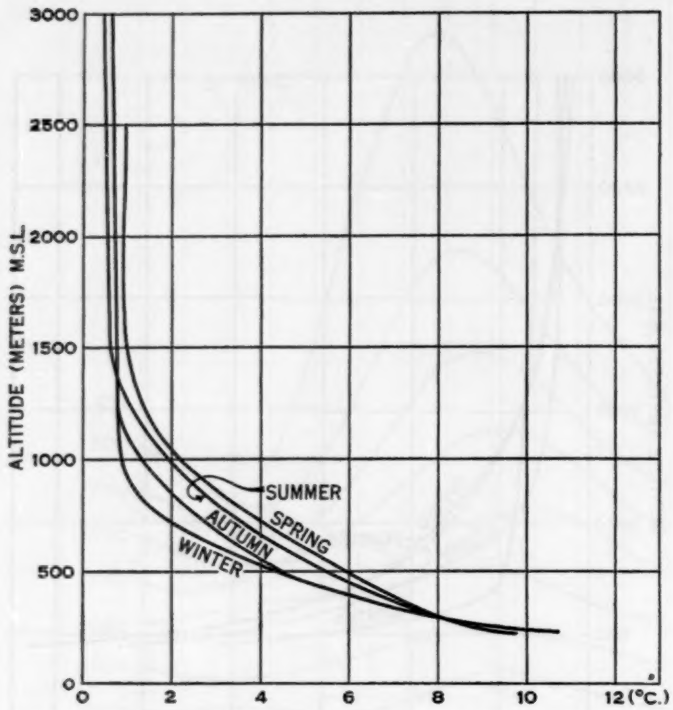

FIGURE 10.—Variation of the diurnal temperature range with altitude at Broken Arrow, Okla.

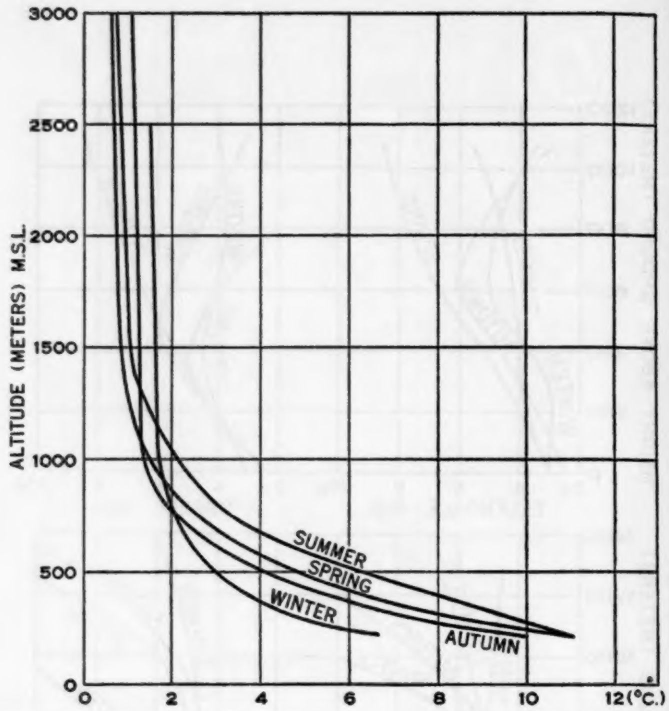

FIGURE 12.—Variation of the diurnal temperature range with altitude at Royal Center, Ind.

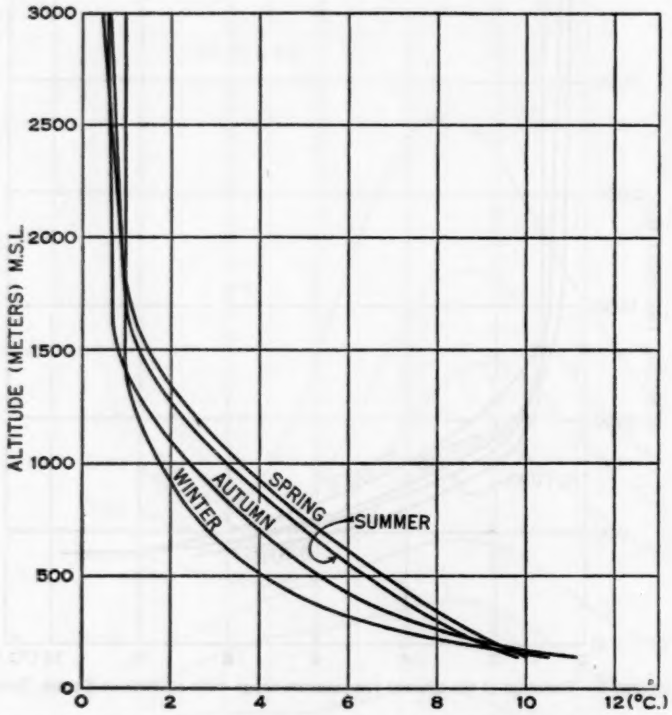

FIGURE 11.—Variation of the diurnal temperature range with altitude at Groesbeck, Tex.

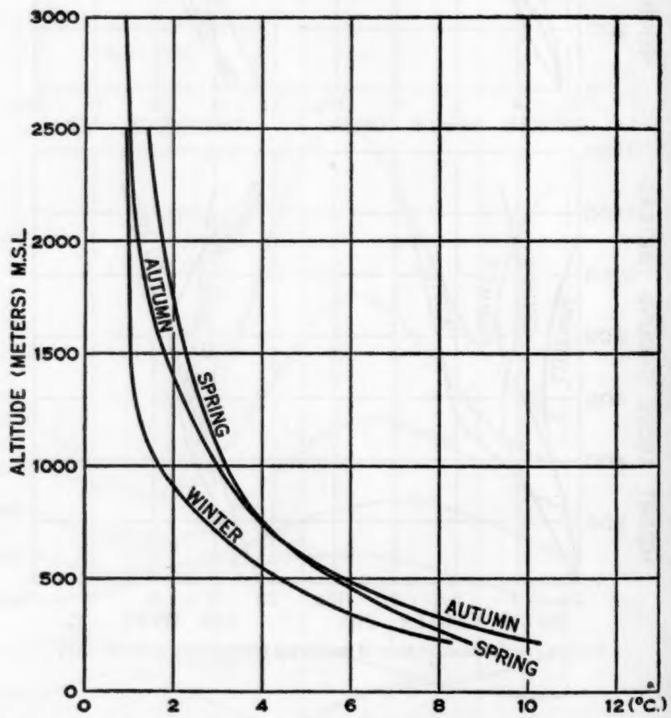

FIGURE 13.—Variation of the diurnal temperature range with altitude at Due West, S.C.

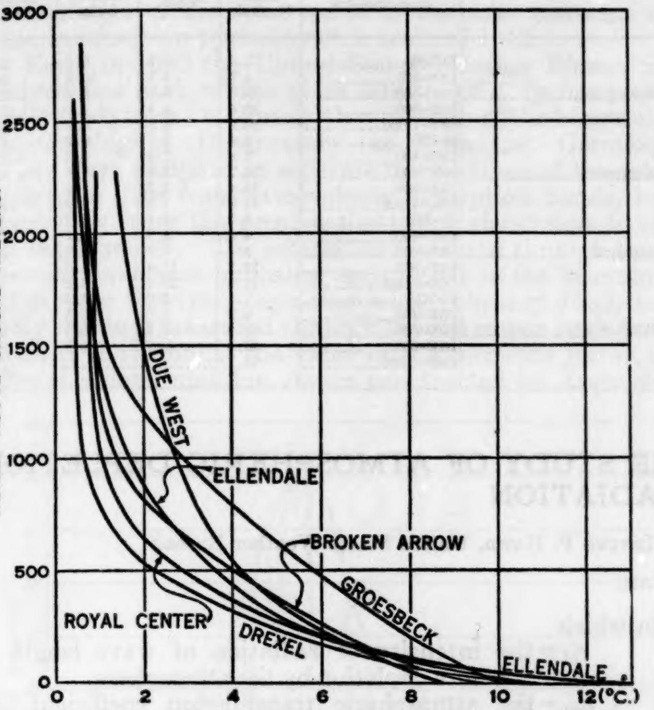

FIGURE 14a.—Variation of the diurnal temperature range with altitude in spring, at various stations.

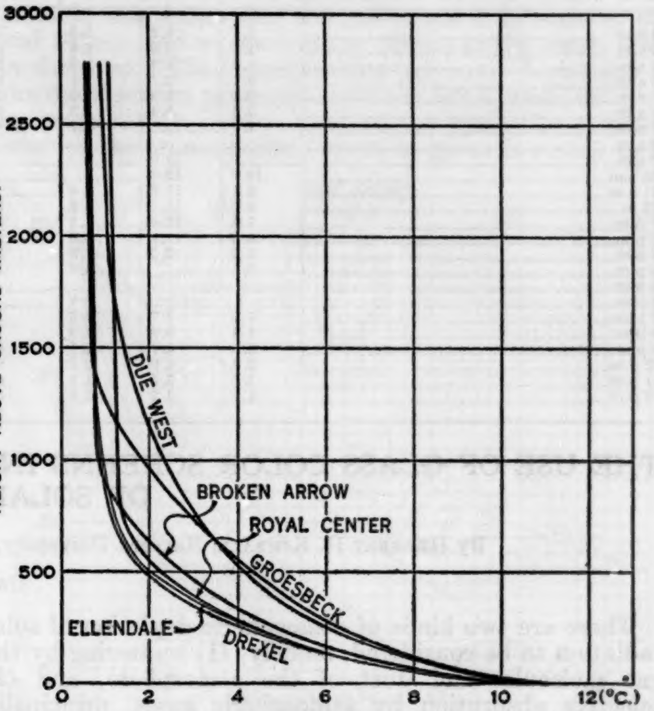

FIGURE 14c.—Variation of the diurnal temperature range with altitude in autumn at various stations.

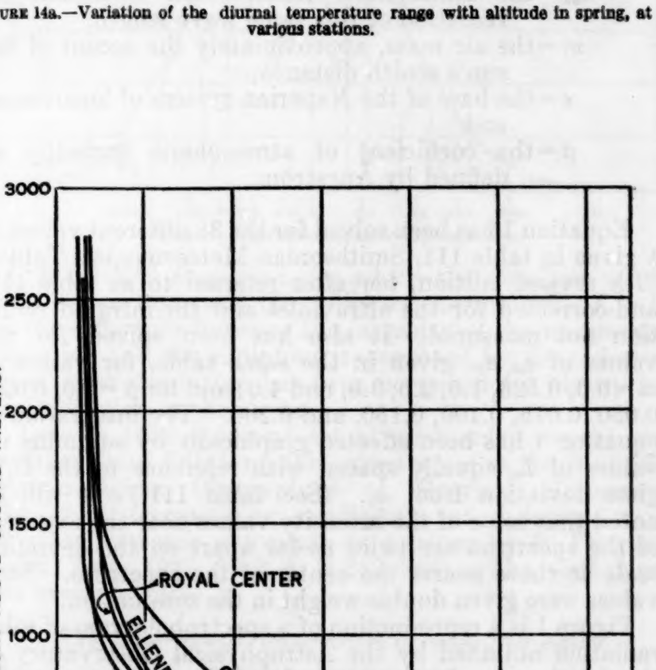

FIGURE 14b.—Variation of the diurnal temperature range with altitude in summer at various stations.

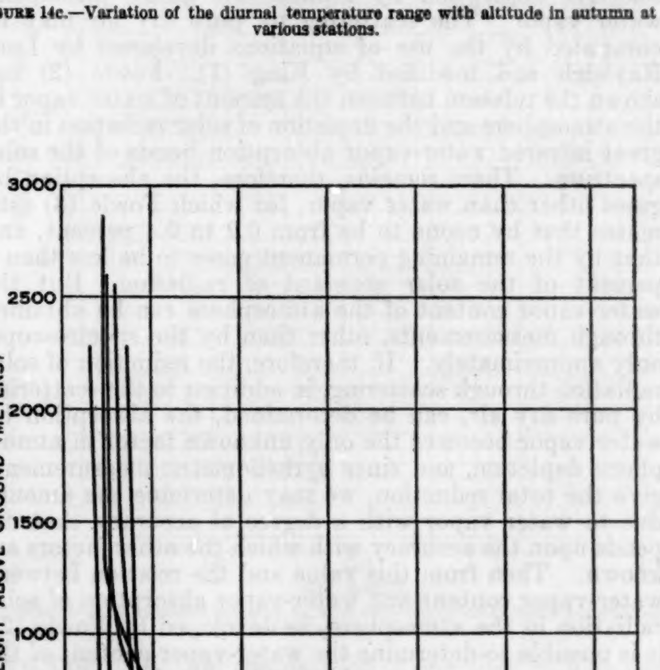

FIGURE 14d.—Variation of the diurnal temperature range with altitude in winter at various stations.

TABLE 6.—*Hourly values of* $(K+K_r)\times 10^{-4}$ *for Drexel, Nebr., for the 750 m, m.s.l., level*

Time	Spring	Summer	Autumn	Winter
1 a.m.	1.1	2.2	1.6	1.5
2 a.m.	1.3	3.2	1.8	2.1
3 a.m.	1.6	3.3	1.6	2.6
4 a.m.	2.1	3.7	1.5	3.0
5 a.m.	2.4	3.8	1.5	2.9
6 a.m.	2.4	3.9	1.2	2.3
7 a.m.	1.7	...	0.7	1.4
8 a.m.	...	...	...	...
9 a.m.	...	13.0	...	...
10 a.m.	10.9	12.0	...	...
11 a.m.	9.1	11.3	6.4	...
12 m.	8.2	11.1	4.8	8.4
1 p.m.	7.4	11.4	4.1	5.6
2 p.m.	6.5	11.7	4.0	3.9
3 p.m.	5.2	12.5	3.8	2.8
4 p.m.	2.5	...	3.8	1.8
5 p.m.	...	...	...	...
6 p.m.	...	...	2.1	...
7 p.m.	7.6	7.7	2.3	2.3
8 p.m.	5.3	5.6	2.3	1.4
9 p.m.	3.8	4.7	2.1	0.9
10 p.m.	2.5	4.0	2.0	0.6
11 p.m.	1.6	3.5	1.8	0.6
12 p.m.	1.2	3.2	1.6	0.9

TABLE 7.—*Values of* $(K+K_r)\times 10^{-4}$ *computed from the diurnal temperature range*

	Height above surface (meters)	Ellendale, N. Dak.	Drexel, Nebr.	Broken Arrow, Okla.	Groesbeck, Tex.
Spring	0-200	3.0	3.3	9.5	29.2
	200-400	4.7	4.1	16.2	29.2
	400-600	19.9	3.4	9.5	29.2
	600-800	13.4	4.4	7.1	21.1
	800-1,000	10.9	8.8	8.8	14.0
Summer	0-200	3.4	5.7	6.9	25.5
	200-400	7.8	7.4	9.5	27.2
	400-600	14.7	5.9	8.8	31.5
	600-800	15.4	5.5	7.4	15.4
	800-1,000	14.0	5.5	5.9	14.0
Autumn	0-200	3.0	2.1	3.2	6.2
	200-400	4.0	3.2	7.1	14.0
	400-600	3.4	4.8	6.8	18.9
	600-800	29.2	15.4	4.0	12.3
	800-1,000	17.9	36.7	8.8	8.8
Winter	0-200	1.2	2.7	3.3	4.1
	200-400	8.8	3.0	3.5	7.1
	400-600	42.9	4.6	2.3	14.7
	600-800	42.9	43.7	6.1	16.2
	800-1,000	31.7	...	...	11.4

THE USE OF GLASS COLOR SCREENS IN THE STUDY OF ATMOSPHERIC DEPLETION OF SOLAR RADIATION

By HERBERT H. KIMBALL, Harvard University, and IRVING F. HAND, United States Weather Bureau

[Apr. 10, 1933]

There are two kinds of atmospheric depletion of solar radiation to be considered, namely, (1) scattering by the gas molecules and dust of the atmosphere, and (2) selective absorption by atmospheric gases, principally water vapor. The scattering by pure dry air may be computed by the use of equations developed by Lord Rayleigh and modified by King (1). Fowle (2) has shown the relation between the amount of water vapor in the atmosphere and the depletion of solar radiation in the great infrared water-vapor absorption bands of the solar spectrum. There remains, therefore, the absorption by gases other than water vapor, for which Fowle (3) estimates that by ozone to be from 0.2 to 0.4 percent, and that by the remaining permanent gases to be less than 1 percent of the solar constant of radiation. But the water-vapor content of the atmosphere can be obtained through measurements, other than by the spectroscope, only approximately. If, therefore, the reduction of solar radiation through scattering, in addition to the scattering by pure dry air, can be determined, the absorption by water vapor becomes the only unknown factor in atmospheric depletion, and since pyrheliometric measurements give the total reduction, we may determine the amount due to water vapor with a degree of accuracy that depends upon the accuracy with which the other factors are known. Then from this value and the relation between water-vapor content and water-vapor absorption of solar radiation in the atmosphere, as developed by Fowle (2), it is possible to determine the water-vapor content of the atmosphere, a matter of considerable importance to meteorologists.

Ångström (4) has shown that the depletion of solar radiation through scattering by dry air containing ordinary atmospheric dust (and he includes in this the scattering that Fowle (2) found associated with water vapor in the atmosphere) may be expressed by $(e^{-\beta/\lambda^{1.3}})^m$. Hence the intensity of solar radiation after depletion by scattering may be expressed by the equation

$$I_m=\int_{\lambda=0}^{\lambda=\infty} e_{o\lambda}\,(a_{a\lambda})^m\,(e^{-\beta/\lambda^{1.3}})^m\,d\lambda \qquad 1$$

in which

$e_{0\lambda}$ = the intensity of radiation of wave length λ before depletion by the atmosphere,

$a_{a\lambda}$ = the atmospheric transmission coefficient for radiation of this same wave length,

m = the air mass, approximately the secant of the sun's zenith distance,

e = the base of the Naperian system of logarithms, and

β = the coefficient of atmospheric turbidity as defined by Ångström.

Equation 1 has been solved for the 38 different values of λ given in table 111, Smithsonian Meteorological Tables, fifth revised edition, hereafter referred to as table 111, and corrected for the ultraviolet and the infrared radiation not measured. It also has been solved for the values of $e_{0\lambda}$ $a_{a\lambda}$ given in the same table, for values of m=0.0, 0.526, 1.0, 2.0, 3.0, and 4.0; and for β=0.0, 0.025, 0.050, 0.075, 0.100, 0.150, and 0.200. The integration of equation 1 has been effected graphically by summing up values of I_m equally spaced with reference to the U.V. glass deviation from ω_1. (See table 111.) It will be noted that some of the intensity values near the extremes of the spectrum are twice as far apart on the deviation scale as those nearer the center of the spectrum. Such values were given double weight in the summation.

Figure 1 is a reproduction of a spectrobologram of solar radiation obtained by the Astrophysical Observatory of the Smithsonian Institution. It will be noted that while the wave lengths change relatively faster at the ultraviolet than at the infra-red end of the spectrum, the prismatic deviation is uniform throughout. It is for this reason that deviations instead of wave lengths are used in connection with computations of radiation intensities in this paper. The results obtained from equation 1 have been plotted on figure 2 and connected by curved lines.

In the integrations no attention has been paid to the water-vapor absorption bands in the infra-red. (See figure 1.) Therefore, the curved lines of figure 2 show

variations in radiation intensity that would prevail in an atmosphere free from water vapor, with the air mass varying from 0.0 to 4.0, and the atmospheric turbidity from 0.00 to 0.200. The intensities are expressed as percentages of the mean value of the solar constant on the Smithsonian pyrheliometric scale of 1913.

Early in 1932 the United States Weather Bureau received one each of the glass screens OG1 (yellow) and RG2 (red) from Dr. Süring, then director of the Magnetic-Meteorological Observatory at Potsdam, Germany. They were designed to separate out sections of the solar spectrum free from atmospheric absorption bands, but especially from the great water-vapor absorption bands in the infra-red. The intensities measured through these screens have been published each month in the MONTHLY WEATHER REVIEW, beginning with February 1932, but only readings measured through the red screen have been used in determining the value of the turbidity factor, β. For this determination curves constructed by Ångström

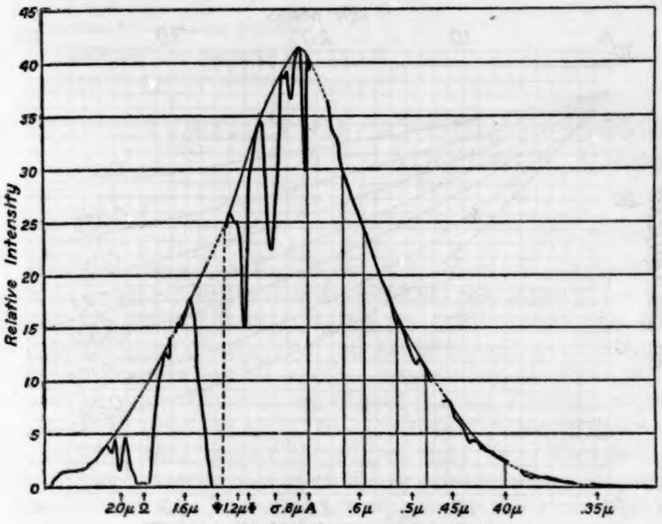

FIGURE 1.—Spectrobologram of solar radiation.

(4) have been employed, for which the abscissas represent the air mass and the ordinates the intensity $I_m - I_r$, or the difference between the intensity of the unscreened radiation and the radiation transmitted by the red-glass filter after the latter has been corrected for absorption and reflection at the screen.

Late in 1932 a second set of glass color screens was received from Potsdam, this time for use at the Blue Hill Meteorological Observatory of Harvard University. For their transmission coefficients at different wave lengths, reference was made to a paper by F. Feussner (Met. Zeit., 1932, Heft 6, S 242–244). The coefficients are given in table 1.

TABLE 1.—*Spectral transmission of Schott filter glasses*

[OG1 (yellow) and RG2 (red)]

Wave length (in $m\mu$)	511	518	522	526	530	535	540	550	560	577	617	622	627	632
Transmission (OG1 in percent)	----	6	29	55	68	78	83.3	87.0	88.2	89.2	89.8	----	----	----
Transmission RG2 in percent	----	----	----	----	----	----	----	----	----	0	(1)	5	18	38

Wave length (in $m\mu$)	637	642	647	652	657	678	698	800	990	1,200	1,370	1,450
Transmission (OG1 in percent)	89.9	----	----	----	89.9	89.9	89.8	89.4	88.6	88.6	88.9	89.3
Transmission RG2 in percent)	60	73	78.8	82.9	85.0	88.3	89.0	88.5	86.8	86.6	87.2	87.6

Wave length (in $m\mu$)	1,750	2,000	2,140	2,250	2,350	2,520	2,650	2,720	2,760	2,820	2,860
Transmission (OG1 in percent)	89.6	89.1	88.0	86.7	86.6	84.9	83.3	68	39	(26)	(23)
Transmission RG2 in percent)	88.3	87.7	86.7	85.0	84.5	83.2	81.0	75	39	(21)	(13)

It will be noted that both these screens drop from a rather high to a low, or even zero, transmission between narrow-wave-length limits. For the yellow screen it is between 518 and $535 m\mu$, and we have taken $526 m\mu$ as the mean point in this drop. For the red screen it is between 622 and $647 m\mu$, and we have taken $636 m\mu$ as the mean point in the drop. The corresponding prismatic deviations on the Smithsonian prismatic scale are 132.5′ and 108′ from ω_1, respectively. Over most of the scale the probable error of the transmission factors as given is stated to be

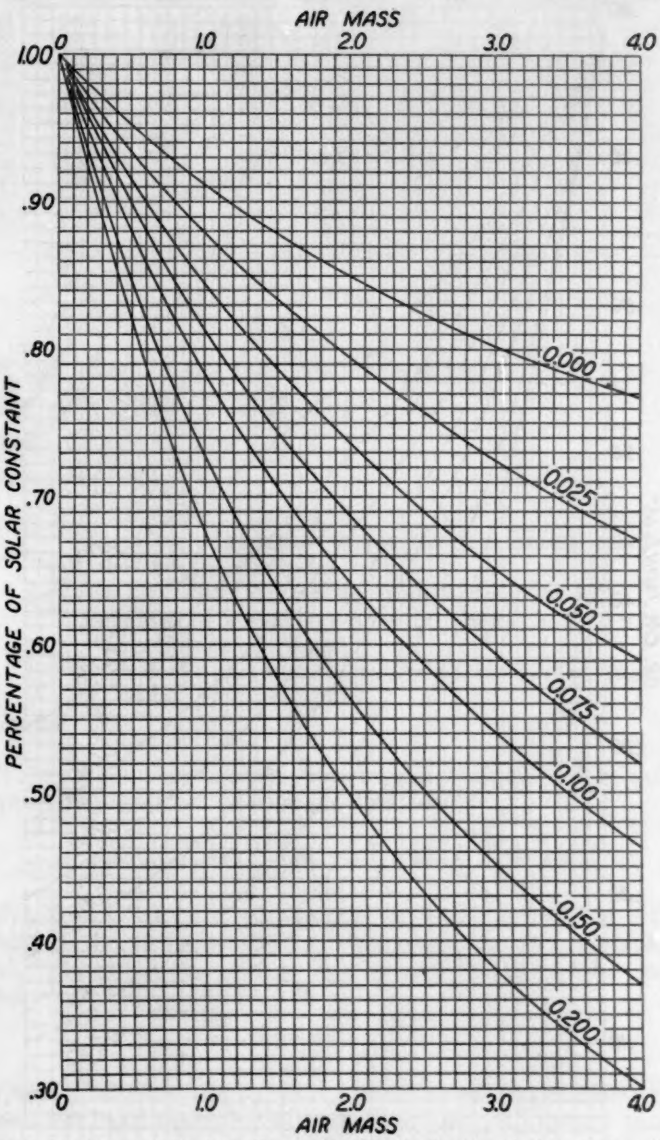

FIGURE 2.—Solar radiation intensity, I_m, after depletion by atmospheric scattering only, for different values of m and β.

± 0.3 percent. For comparision of one filter with another it is placed at ± 0.5 percent.

Unfortunately neither filter, OG1 nor RG2, cuts off at exactly the same wave length in different samples of the screens. Ångström suggests that this be taken care of by a correction to the transmission determined for an average screen. This would require a standardization of each screen received, at least for the shorter wave lengths. This has not been done either for the screens in use at the United States Weather Bureau or for those at Blue Hill.

Applying the transmission coefficients of the respective filters for given wave lengths to $e_{o\lambda}\, a_{a\lambda}$ (energy distribution for pure dry air, table 111) we have obtained for the transmission of the red screen, RG2, 87.8 percent, for

$\lambda > 526m\mu$, and for the yellow screen, OG1, 88.9 percent, for $\lambda > 636m\mu$.

It appears that for different spectral distributions of solar radiation, as for instance that given in the last column of table 111, slightly different transmission coefficients would be found.

If now we take the difference $I_m - (I_y/0.889)$ we have left $\Sigma I_m(\lambda < 526m\mu)$ which represents the intensity of the

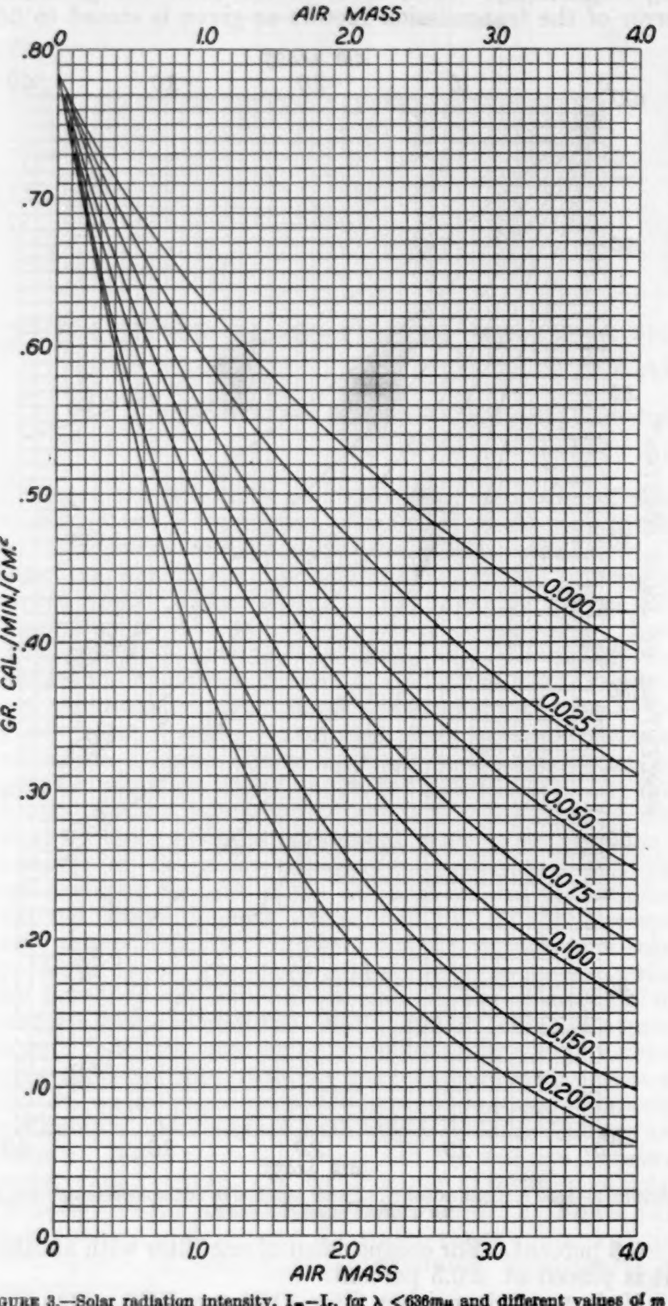

FIGURE 3.—Solar radiation intensity, $I_m - I_r$, for $\lambda < 636m\mu$ and different values of m and β.

radiation in a part of the spectrum where there are few absorption bands. Similarly, and perhaps preferably, if we take the difference $I_m - (I_r/0.878)$ we have left $\Sigma I_m(\lambda < 636m\mu)$, also in a part of the spectrum where there are few atmospheric absorption bands, and which contains a greater proportion of the total spectrum than does $\Sigma I_m(\lambda < 526m\mu)$.

Values of $\Sigma I_m(\lambda < 636m\mu)$, for different values of m and β are plotted in figure 3, with m as abscissas and $\Sigma I_m(\lambda < 636)$ as ordinates.

If we take the difference $\Sigma I_m \lambda < 636m\mu - \Sigma I_m \lambda < 526m\mu$, we have a measure of the intensity of solar radiation in a part of the spectrum free not only from depletion by atmospheric absorption, but also from the ultra-violet radiation where the intensity is not well known. These values have been plotted in figure 4, with m as abscissas and intensities ΣI_m $(636m\mu > \lambda > 526m\mu)$ as ordinates.

Evidently, having constructed figures 2, 3 and 4, we may determine the value of β at the time and for the value of m at which a measurement of $I_m - I_r$, or $I_y - I_r$, was obtained, by interpolating in figure 3 or figure 4, respectively. Having found β, interpolation in figure 2 will give the solar radiation intensity that would have been found for the same value of m with an atmosphere free from moisture, and I_m $(w=0) - I_m =$ the atmospheric absorption of solar radiation.

Finally, referring to Smithsonian Meteorological Tables, 1931, p. lxxxlv, figure 1 (see, also, this REVIEW, February 1930, p. 52), interpolation between curves 2 to

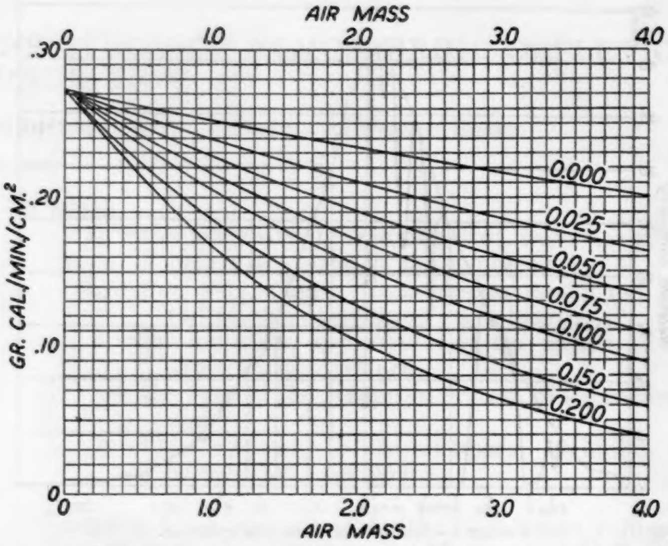

FIGURE 4.—Solar radiation intensity, $I_y - I_r$, for $526 < \lambda < 636m\mu$ and for different values of m and β.

8 and 9 to 15, respectively, as the value of $(I_m(w=0) - I_m)$ requires, will give the water-vapor content of the atmosphere w, expressed in centimeters of precipitable water. An example of these various determinations is given in table 2.

The values obtained for both β and w are smaller than we would expect, and for w they are smaller than are indicated by the psychrometically determined surface water-vapor pressure. It is suspected that the reason for this may be due to the fact that for the screens in use at Washington the value of λ at which the transmission coefficients become zero are somewhat lower than the values we have been led to adopt from the transmission coefficients given in table 1. Exactly what this should be can only be determined by a special calibration of our screens.

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TABLE 2.—*Computations of the atmospheric turbidity factor, β, and the water-vapor content of the atmosphere, w, from screened solar radiation measurements*

[From measurements at Washington, D.C. April 18, 1932]

Air mass m	Atmospheric turbidity β								Water-vapor content of the atmosphere, w (cm)					
	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)[b]	(15)[c]
	I_m	$\frac{I_r}{0.878}$	$\frac{I_y}{0.889}$	(2−3)[a]	(4−3)[a]	β from (5)	β from (6)	Mean (7)+(8)	I_m (w=0)	I_m	(10)−(11)	w (Cm)	Mm	Mm
									Percentage of solar constant					
3.99	0.881	0.700	0.790	0.183	0.091	0.077	0.098	0.088	0.490	0.459	0.031	0.16	0.70	----------
3.23	1.002	.737	.870	.268	.133	.065	.072	.078	.592	.522	.070	.39	1.75	----------
3.10	1.027	.747	.881	.283	.135	.062	.074	.068	.602	.536	.066	.35	1.57	----------
2.47	1.118	.778	.939	.343	.161	.060	.064	.062	.668	.582	.086	.49	2.20	----------
2.37	1.137	.782	.943	.359	.161	.058	.071	.064	.672	.592	.081	.47	2.11	3.63
1.83	1.223	.834	1.016	.393	.182	.064	.061	.068	.719	.637	.082	.50	2.24	----------
1.79	1.229	.837	1.022	.396	.185	.072	.069	.070	.719	.640	.079	.49	2.20	----------
1.57	1.296	.856	1.048	.444	.193	.063	.077	.065	.753	.675	.078	.49	2.20	----------
1.52	1.303	.859	1.060	.448	.201	.065	.060	.066	.757	.679	.078	.50	2.24	----------
1.44	1.326	.862	1.065	.469	.203	.059	.060	.060	.785	.691	.094	1.00	4.48	----------
1.40	1.338	.863	1.069	.480	.206	.053	.061	.057	.785	.697	.088	.95	4.26	----------
1.32	1.354	.843	1.073	.516	.230	.043	.025	.034	.883	.705	.128	1.41	6.32	----------
1.15	1.428	.913	1.124	.520	.211	.056	.073	.064	.805	.744	.061	.69	3.09	3.15
1.46	1.284	.846	1.053	.442	.207	.074	.055	.064	.765	.669	.096	1.01	4.49	----------

[a] Corrected for mean solar distance.

[b] Surface water-vapor pressure $=\frac{w}{.223}$

[c] From psychrometer measurements.

CONSERVATION OF ANGULAR MOMENTUM, OR AREAS, AS APPLIED TO AN AIRPLANE EN ROUTE TO THE POLE

By W. J. HUMPHREYS

[Weather Bureau, Washington, April 1933]

When a freely moving object is held on its course by a pull or push continuously directed to the same point, as illustrated by a planet tracing its orbit about the sun under the force of gravity, the areas swept over by the straight line, or radius vector, connecting the center of attraction with the moving object during different equal intervals of time are equal to each other, however near to or far from that center the object may be. This is the law of the conservation of areas, or conservation of angular momentum. The same law applies to the atmosphere, barring the effects of friction and turbulence, when forced to change latitude. In this case the radius vector is the perpendicular from the place occupied onto the axis of the earth, or radius of the small latitude circle through the place in question.

Rigid proofs of these laws are well known, though few books contain them in detail. They are based on, or in keeping with, the conservation of energy, hence without exception and not in the least contravened by the fact that the air in high latitudes often is just as quiet as that of any other part of the world. However, one may accept the logical proofs of all these statements and still be puzzled by the fact that one can fly to either pole of the earth, as has been done, without being driven into a dizzy west-to-east spin about it.

If the law of the conservation of areas is true, and if the force driving the plane seems all the time directed strictly towards the pole, then why is it that the plane, instead of spinning around the world from west to east, at an ever-increasing speed, keeps to the same meridian?

The law, as stated, is true, and the plane is kept from speeding eastward by a counter force—the driving force is not strictly towards the pole.

How great then is this counter force?

Let the conditions be:

Latitude of plane, $\lambda=80°$.

West-to-east velocity of plane same as earth beneath, $u=\frac{2\pi R\cos\lambda}{T}=\frac{2\pi r}{T}$.

R = Radius of the earth.

T = Time of rotation of the earth (siderial day) = 86,164 seconds.

r = Radius of circle of latitude at latitude λ.

Velocity of plane towards adjacent pole, v=200 kilometers per hour.

By the law of the conservation of areas, ur = constant.

Hence $\frac{du}{u}=-\frac{dr}{r}$

Then, if s is a distance along a meridian (approach to pole positive) the west-to-east acceleration

$$\frac{du}{dt}=-\frac{u}{r}\frac{dr}{dt}=\frac{u}{r}\frac{ds}{dt}\sin\lambda=\frac{u}{r}v\sin\lambda=\frac{u}{R}v\tan\lambda$$

When u is equal to the west-to-east velocity of the surface of the earth at the place in question, that is, when the plane has no motion across the meridian, the last expression,

$$\frac{u}{R}v\tan\lambda=\frac{2\pi v\sin\lambda}{86164}$$

On substituting the value of v in terms of centimeters and seconds, and the value of $\sin\lambda$ for $\lambda=80°$, it appears that, under the conditions stated, $\frac{du}{dt}=0.4$ cm/sec.^{2}, nearly, or about 1/2450 part of gravity acceleration. The maximum value, as the pole is reached, is but little greater.

Now the ratio of thrust to the lift, in the case of an airplane, is, roughly, 1 to 8. Hence, in the above case, an east-to-west push equal to about one 300th that of the poleward thrust would fully counteract the effect of the law of the conservation of areas and keep the plane on the same meridian. This would be accomplished by heading the plane rather less than one fifth of a degree west of the true meridian, an amount that would seem to the aviator, if noticed at all, as a mere drift correction.

The law of the conservation of areas is true, nevertheless it does not perceptibly interfere with the interzonal travel of airplanes, even to the poles of the earth.

TORNADO AT NASHVILLE, TENN., ON MARCH 14, 1933

By R. M. WILLIAMSON

[Weather Bureau Office, Nashville, Tenn., Apr. 5, 1933]

About 7:30 p.m. of Tuesday, March 14, 1933, Nashville was visited by a rather severe tornado, undoubtedly the worst storm in its history and certainly the most damaging. The day had been warm, the maximum temperature reaching 80° at 3 p.m. It was as high as 76° as late as 6:30 p.m. At that time a thunderstorm was approaching from the southwest, five tenths of cumulonimbus clouds being observed and the first thunder heard at 6:45 p.m.

An extensive area of low pressure, with two centers, occupied the Eastern States at 7 a.m. of the 14th (central standard time). This was a fairly good type of V-shaped depression, with a decided southwest-northeast trend. One center was over the Great Lakes and the other over western Arkansas and southern Missouri, the lowest pressure in the latter area being 29.56 inches at Fort Smith, Ark. At 4 p.m. the southern portion of the depression was long and narrow, extending from Memphis Tenn., to Columbus, Ohio, being wedged in between high pressure areas in the southeast and in the northwest. At the p.m. observation the trough extended from Nashville, Tenn., to Parkersburg, W.Va., both points registering the same pressure, 29.62 inches. There probably was slightly lower pressure at the Lexington, Ky., station, where it is indicated on the Washington weather map that the center was located at 7 p.m. The tornado struck Nashville 45 minutes after the above barometer reading was made. It therefore occurred in the southeast quadrant of the depression, and somewhat ahead of the wind-shift line at the surface.

The wind direction had been southwest most of the afternoon, becoming south-southwest at 6 p.m. and south at 6:50 p.m. Here it remained until 7:18 p.m., when the approaching thunderstorm brought the usual shift to an easterly direction (in this case, southeast). For about 10 minutes the wind blew from the southeast. Suddenly at 7:28 p.m. the wind veered from southeast to southwest, remaining so for 1 minute, and at 7:30 p.m. it was blowing from the west. The wind velocity at 7:20 p.m. was at the rate of 15 miles per hour; the velocity increased to 27 miles per hour at 7:26 p.m., 47 miles per hour at 7:27 p.m., and 65 miles per hour at 7:28 p.m. This was the extreme velocity at the station. For the 5-minute period beginning at 7:26 p.m. the average velocity was 50 miles per hour. During the minute of blow from the southwest the tornado was passing just north of the station, the right side of the path of destruction being only about 400 feet away. After the passing of the storm the wind direction was west for 15 minutes, northwest for 20 minutes, west-southwest for 15 minutes, and finally northwest for the remainder of the night.

Large hailstones preceded the arrival of the tornado by several minutes and heavy rainfall began with the shift of wind to the west. The temperature dropped from 75° at 7:30 p.m. to 61° at 8 p.m., due to cooling caused by the thunderstorm. The temperature then remained nearly stationary for about 1 hour. From 9 p.m. to 10 p.m. there was a further drop of 10° to 51°. This was the result of the progress eastward of the high-pressure cold-weather area, following the permanent shift of the wind to the northwest. In other words, the thunderstorm and the tornado were running ahead of the cold northwest blast at the surface about 1 hour. The tornado was not coincident with but preceded the real wind shift line by about 1 hour.

As the thunderstorm neared the station the barograph trace was falling with fair speed. About 7:30 p.m. it dropped suddenly 0.12 inch and immediately recovered 0.15 inch. This was during the passing of the tornado. The rise in pressure continued for probably 20 minutes, when there was another slight fall, lasting about 15 to 20 minutes. This second drop in pressure, after the thunderstorm had passed, was just prior to the permanent shift of wind from west-southwest to northwest at which time a steady rise in the barometer began.

Assistant Meteorologist Foster V. Jones, who was on duty at the Weather Bureau office until 7 p.m. and who later observed the approaching storm from his home at Delmas Avenue and Gallatin Pike, about three fourths mile north of the tornado's path, described its appearance as follows: "The tornado cloud was first observed while watching the unusual hail which fell prior to the storm. The cloud approaching from a westerly direction appeared like a huge inverted cone moving rapidly across a light-colored background of rain, looking very much similar to a shadow moving across a motion-picture screen." The usual roar, as of a freight train thundering along at high speed, was attested by many.

The path of the storm across the city was approximately east-northeast. It first appeared in west Nashville in the vicinity of Charlotte Pike and Fifty-first Avenue, about 4 miles from the public square. So far as known, this was the point of origin of the storm. From that vicinity to the public square moderate damage occurred here and there, such as trees broken off and a few walls down. Upon reaching Capitol Hill it caused the breaking of a few windows in the State Capitol Building and then descended upon the buildings on the north and east sides of the public square with terrific fury. The path here was probably not over 200 yards wide but the destruction was great. Some 15 or more brick business houses, ranging from 3 to 5 stories high, were affected. The top stories of some of the buildings on the east side of the square had both the west and the east ends blown out, the main portion of the roof remaining intact. Several on the north side of the square were almost completely demolished. Proceeding thence across Cumberland River the storm widened to about 400 yards and partially wrecked a row of 4-story factory buildings along First Street, and greatly damaged another large brick building, occupied by the National Casket Co., at Second and Woodland Streets. Large sections of brick wall a foot or more in thickness gave way to the pressure. From this point, for a distance of 3 miles it tore through a district of residences, churches, schools, and store houses, the width of the path ranging from 600 to 800 yards.

The total length of the path across the city was about 8 miles, but the storm's track can be traced through Davidson County, Wilson County, and into Smith County, a total distance of about 40 miles. Mr. Jones followed the course of the storm for several miles east of the city, and has the following to say regarding its path:

> Taking a map of the city of Nashville and considering the greatest destruction as the center of the path it is found that the tornado was traveling easterly at an angle ranging from 20° to 30° north of east in the city proper, but describing a very slight arc to the south as it advanced beyond the city limits and across Davidson County into Wilson County. It crossed the Davidson County line near Tulip Grove, thence moved eastward through Lebanon to the Smith County line, apparently spending itself within Smith County.

The width of the path is very irregular, varying from one city block near the center of Nashville to slightly over a mile at a point 8 miles east of the city, then narrowing to only a hundred yards or so within a very short distance. At Lebanon the path was about 200 yards wide. The wider the path, the less destruction, in all cases. At the widest point the destruction was confined largely to the topping of trees, although some buildings near the center of the area exploded due to the decrease in pressure.

It was decided that only one tornado occurred in the counties named; and that it was a true funnel type tornado cloud, traveling in an easterly direction approximately 35 miles an hour, pulsating earthward with the apex swinging perpendicularly across the path.

Evidences of tornadic action were so plain and so numerous that no one questioned the true nature of the storm. A 2- by 4-inch timber was driven endwise into the east slope of the roof of the writer's home, clearly the result of a counterclockwise wind blowing into a vortex. At many places in the beautifully wooded portions of East Nashville uprooted trees along the outer edges of the whirl, of which there were hundreds, lay practically at right angles to the direction of the storm's path and toward the center. Hundreds of buildings showed the explosive effect of the storm—roofs lifted and walls blown outward. Many of these were completely demolished. Frame structures succumbed to the fury of the storm more readily than brick and stone, but the latter were by no means spared. Wreckage of many large brick buildings occurred and the damage was great. Notable among such examples were the brick buildings on the square and those just across the river, already referred to, the new East Nashville High School, where the roof of the large gymnasium was lifted off, and the new Bailey High School, which was more than half wrecked. It was observed that walls or roofs inclosing large rooms almost invariably gave way first under the unusual pressure, such pressure exerting full force against the outer inclosures instead of being divided by inside partitions. Numbers of persons in the storm area experienced difficulty in hearing and suffered discomfort in their ears for several days after the storm, due to the suddenly reduced pressure.

The tornado killed 11 persons in Nashville and injured scores of others. The small loss of life was one of its remarkable features, considering the fact that it traversed an area occupied by about 10,000 persons. The property damage included 1,400 homes, of which 1,100 were frame structures and 300 brick or stone; also 16 churches, 36 stores, 5 factories, 4 schools, 1 library, and 1 lodge hall. Some of the best residences of East Nashville were among the damaged list. The property loss within the city, exclusive of trees, automobiles, and other personal property, was estimated at $1,450,000, and in the suburbs $150,000. Loss of personal property is estimated at $400,000. This tornado killed four persons in Lebanon and caused property damage of about $125,000. Its total loss of life was 15 persons and the total property loss probalby $2,200,000.

The writer, who was near the center of the storm's path on Eastland Avenue, fortunately (for him) did not attempt to observe the storm's approach, for a look out a rear door or window might have cost him his life. During the terrifying half minute when walls, roofs, chimneys, garages, and trees were crashing only a few yards away and his own house was quivering under the pressure and was partially demolished, he and his family were in the front of the house and were unharmed, in spite of a feeling of intense expectancy. Numbers of his neighbors, however, were less fortunate. Some were crushed in the wreckage and others were blown out with the walls, landing in adjoining yards. If it were possible to keep doors and windows open during such a blow, relieving somewhat the inside pressure, the walls and roof of a building might not suffer, but the contents, including the occupants themselves, would be sucked into the open and made targets for flying debris.

Many interesting and freakish things occurred, the following being observed by the writer:

A corn stalk was found driven endwise through a piece of weather boarding.

A 2- by 4-inch timber plunged through a panel door without causing the slightest splitting or splintering. The timber fit the opening perfectly.

A 1- by 6-inch plank was forced through the trunk of a sturdy young tree, splitting the tree in half.

A high-tension tower was bent to the ground in a tangled mass without breaking loose from its concrete moorings.

It is not believed that this tornado was as violent as many that have occurred in other States, nor even in Tennessee for that matter, else the loss of life and property would have been much greater. Its significance lies in the fact that it pierced the heart of one of our large cities.

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C. FITZHUGH TALMAN, in Charge of Library

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING MARCH 1933

By IRVING F. HAND, Assistant in Solar Radiation Investigations

For a description of instruments and their exposures, the reader is referred to the January 1932 REVIEW, page 26.

Table 1 shows that solar radiation intensities averaged above normal for February at Washington and Madison, and close to normal at Lincoln.

Table 2 shows an excess in the total solar radiation received on a horizontal surface at all stations except Madison, Lincoln, Pittsburgh, and La Jolla.

Table 3 shows the effect of cirri on turbidity factors; particularly on the 27th.

Polarization measurements made on 5 days at Washington give a mean of 49 percent with a maximum of 54 percent on the 29th. These are slightly below normal for the month. No polarization readings were obtained at Madison due to the presence of ice and snow.

TABLE 1.—*Solar radiation intensities during March 1933*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D.C.

Date	Sun's zenith distance. 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A.M.					P.M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e
	mm	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm
Mar. 6	2.62	0.87	1.08	1.22	1.29						1.45
Mar. 8	5.16	.83	1.05	1.14	1.32	1.58					4.57
Mar. 9	2.11						1.19				1.24
Mar. 17	3.81					1.29					4.75
Mar. 27	3.15	.47	.59	.77							2.74
Mar. 28	4.17				.88						3.99
Mar. 29	2.74	.80	.91	1.03	1.26	1.43	1.21				3.00
Means		.74	.91	1.04	1.19	1.43	(1.20)				
Departures		+.01	+.10	+0.09	+.04	±0.00	+0.07				

TABLE 1.—*Solar radiation intensities during March 1933*—Contd.

Madison, Wis.

Date	Sun's zenith distance. 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A.M.					P.M.				Local mean solar
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e
	mm	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm
Mar. 1	1.68			1.26	1.44	1.67					2.36
Mar. 2	2.74						1.50				3.45
Mar. 10	.86		1.04	1.25	1.50	1.61	1.24				1.02
Mar. 15	1.68		1.08	1.20	1.38	1.61	1.41				1.60
Mar. 22	2.36		1.03	1.10	1.34	1.64	1.46				2.49
Mar. 24	2.49		.83	.97							3.45
Mar. 27	4.75				1.08						3.81
Means			1.00	1.16	1.35	1.63	1.40				
Departures			−.04	−.01	+.03	+.04	+.10				

Lincoln, Nebr.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Mar. 2	2.74				1.10		1.20	0.99	0.90	0.80	2.62
Mar. 3	2.74						1.25	1.05	.90	.74	3.30
Mar. 11	2.87	0.74	0.87	1.06	1.24	1.45					4.17
Mar. 13	8.81				1.16	1.38	1.22	1.02	.89	.77	6.76
Mar. 15	3.00	.87	1.00	1.16	1.33	1.52					3.63
Mar. 16	3.63					1.28	1.13	.99	.80	.67	3.63
Mar. 21	1.60	.96	1.08	1.22	1.42	1.57	1.37	1.21	1.08	.99	2.36
Mar. 23	3.63			1.10	1.29						3.45
Mar. 27	4.57						1.30	1.10	.93	.87	4.37
Mar. 31	5.56						1.27	1.09	.96	.85	5.56
Means		.86	.98	1.14	1.26	1.44	1.25	1.06	.92	.80	
Departures		+.02	+.04	+.05	−.01	−.08	−.03	−.03	−.02	−.01	

Blue Hill, Mass.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Mar. 5	2.2				1.37	1.50					2.2
Mar. 6	1.5				1.30	1.62	1.31				1.8
Mar. 9	2.6						1.22	0.89			2.7
Mar. 10	1.6				1.28						1.5
Mar. 11	1.2			1.21	1.38	1.56	1.36				1.5
Mar. 12	2.0			.85	.92						2.2
Mar. 16	2.2			1.15	1.35	1.58	1.36	1.17			2.3
Mar. 24	3.1				1.13		1.18				3.1
Mar. 25	3.4				1.17	1.52					3.3
Mar. 27	3.8					1.44	1.19	.98			3.4
Mar. 30	2.3				1.30	1.51	1.30				2.2
Means				1.07	1.24	1.53	1.27	1.01			

[1] Extrapolated.

TABLE 2.—*Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface*

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Fresno	Pittsburgh	Fairbanks	Twin Falls	La Jolla	Gainesville	Miami	New Orleans
	Gram calories per square centimeter												
1933	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Feb. 26	335	254	348	229	248	454	184	172	343	243	381	410	272
Mar. 5	582	272	335	249	319	381	237	158	352	299	443	392	288
Mar. 12	292	271	370	217	268	402	210	207	348	362	444	475	237
Mar. 19	150	275	355	150	211	537	107	205	401	365	385	443	372
Mar. 26	378	248	410	253	297	500	265	241	403	361	500	480	328
	Departures from weekly normals												
Feb. 26	+45	−27	+9	+29	+12	+70	−2		+43	−90	−30	+26	
Mar. 5	+252	−28	−18	+45	+54	±0	+33		+39	−39	+45	−15	
Mar. 12	−35	−46	−5	+9	−5	+2	−7		+19	+13	+45	+39	
Mar. 19	−198	−42	−39	−59	−58	+79	−119		+53	−9	±0	−15	
Mar. 26	+30	−100	+2	+9	+17	+2	+14		+17	−42	−4	+4	
	Accumulated departures on Apr. 2, 1933												
	+2,394	−2,191	−924	+2,562	+2,282	+2,191	+553		+1,099	−1,568	−5,131	−567	

TABLE 3.—*Solar-radiation measurements, and determinations of atmospheric turbidity factor, β, Washington, D.C., March 1933*

Date and solar hour angle	Solar altitude, h	Air mass, m	I_m cal.	I_y cal.	I_r cal.	β	Blueness of sky	Atmospheric dust particles per cubic centimeter	Notes: Skylight polarization, P, clouds, etc.
1933 Mar. 6									
3:54 a	20-01	2.90	1.225	0.877	0.738	0.040		914	
3:48 a	21-03	2.77	1.244	.928	.744	.040			
3:44 a	21-45	2.69	1.269	.934	.756	.038			
3:40 a	22-26	2.61	1.280	.936	.759	.035			
2:46 a	31-16	1.92	1.285	.880	.735	.060	5		P=51.2%
2:42 a	31-20	1.92	1.257	.880	.735	.070			Cirri.
Mar. 9									
4:18 a	16-34	3.48	1.079	.791	.665	.042		275	
4:12 a	17-34	3.28	1.105	.797	.667	.040			
3:35 a	24-10	2.43	1.217	.881	.707	.045			
3:29 a	25-10	2.34	1.250	.879	.712	.040			
2:40 a	32-54	1.84	1.340	.918	.746	.045	5		P=48.2%
2:37 a	33-29	1.81	1.360	.921	.747	.045			
1:27 a	42-08	1.49	1.444	.921	.735	.040			
1:20 a	42-47	1.47	1.463	.922	.735	.035			
Mar. 27									
4:51 a	15-00	3.82	.645	.488	.447	.130		899	
4:48 a	15-36	3.68	.644	.491	.450	.135			
4:27 a	19-40	2.95	.753	.569	.516	.165			Cirri.
4:22 a	20-35	2.82	.787	.571	.521	.165			
3:51 a	26-34	2.23	.816	.635	.537	.180			
3:47 a	27-18	2.17	.832	.638	.540	.180	4		P=42.6%
Mar. 29									
4:57 a	14-24	3.98	.909	.688	.591	.065		317	
4:54 a	14-58	3.84	.922	.691	.596	.065			
4:33 a	19-02	3.05	1.029	.765	.647	.075			
4:28 a	19-56	2.92	1.058	.769	.650	.065			
4:20 a	21-36	2.70	1.075	.794	.671	.078			
4:16 a	22-12	2.63	1.106	.797	.672	.072			
3:51 a	26-51	2.21	1.211	.853	.700	.060			
3:47 a	27-35	2.15	1.236	.856	.700	.052	6		P=53.7%
2:13 a	43-22	1.46	1.353	.888	.700	.105			
2:09 a	43-56	1.44	1.338	.891	.700	.115			
0:55 a	52-20	1.27	1.424	.935	.759	.068			
0:51 a	52-40	1.26	1.429	.938	.759	.068			
1:36 p	48-19	1.34	1.350	.950	.774	.110			
1:42 p	47-36	1.36	1.306	.953	.771	.140			
2:43 p	38-42	1.60	1.295	.884	.694	.140			
2:47 p	37-40	1.63	1.301	.887	.694	.140			
3:26 p	31-14	1.93	1.218	.860	.694	.135			
3:30 p	30-42	1.95	1.221	.863	.697	.135			

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Perkins, and Mount Wilson Observatories. The differences of latitude are measured from central meridian, positive west. The north latitude are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1933	h.	m.	°	°	°			
Mar. 1 (Naval Observatory)	11	56	−64.0	305.4	+13.0		123	123
Mar. 2 (Mount Wilson)	12	0	−51.0	305.2	+14.0		223	
			−23.0	333.2	+9.0	11		234
Mar. 3 (Naval Observatory)	11	34	−37.0	306.3	+13.0		93	93
Mar. 4 (Naval Observatory)	11	35	−24.0	306.1	+13.0		93	93
Mar. 5 (Perkins Observatory)	16	0	−13.5	301.0	+13.0		90	
			−4.5	310.0	+16.5		90	180
Mar. 6 (Naval Observatory)	11	9	+3.0	307.0	+13.0		93	93
Mar. 7 (Mount Wilson)	12	35	+16.0	306.0	+14.0		118	118
Mar. 8 (Naval Observatory)	11	51	+24.0	301.2	+11.0		9	
			+33.0	310.2	+15.0	77		86
Mar. 9 (Naval Observatory)	10	5	+37.0	302.0	+11.0		9	
			+46.0	311.0	+15.0	77		86
Mar. 10 (Naval Observatory)	11	8	+60.0	311.3	+15.0	77		77
Mar. 11 (Naval Observatory)	11	49	+74.0	311.7	+15.0	77		77
Mar. 12 (Perkins Observatory)	14	0		No spots				
Mar. 13 (Mount Wilson)	11	30		No spots				
Mar. 14 (Mount Wilson)	12	25		No spots				
Mar. 15 (Naval Observatory)	10	58		No spots				
Mar. 16 (Naval Observatory)	11	35		No spots				
Mar. 17 (Naval Observatory)	11	44		No spots				
Mar. 18 (Mount Wilson)	11	0		No spots				
Mar. 19 (Mount Wilson)	10	50		No spots				
Mar. 20 (Mount Wilson)	10	45		No spots				
Mar. 21 (Mount Wilson)	11	0		No spots				
Mar. 22 (Naval Observatory)	13	28	−73.0	18.8	+4.0		401	401
Mar. 23 (Mount Wilson)	11	45	−58.0	21.5	+5.0		408	408
Mar. 24 (Naval Observatory)	13	44	−45.0	20.3	+4.0		216	216
Mar. 25 (Mount Wilson)	11	30	−32.0	21.3	+5.0		234	
			+20.0	73.3	+10.0		31	265
Mar. 26 (Naval Observatory)	12	44	−18.0	21.5	+4.0		247	
			+35.0	74.5	+10.0		77	324
Mar. 27 (Mount Wilson)	11	15	−5.0	22.1	+5.0		200	
			+49.0	76.1	+10.0		44	244
Mar. 28 (Naval Observatory)	11	20	+8.0	21.9	+5.0		185	
			+62.0	75.9	+10.0		93	278
Mar. 29 (Naval Observatory)	10	54	+22.0	22.9	+5.0		170	170
Mar. 30 (Naval Observatory)	11	13	+36.0	23.5	+5.0		123	123
Mar. 31 (Mount Wilson)	11	10	+49.0	23.3	+4.0		131	131
Mean daily area for March								123

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Perkins, and Mount Wilson Observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR MARCH 1933

[Dependent alone on observations at Zurich and its station at Arosa]

[Data furnished through the courtesy of Prof. W. Brunner, University of Zurich, Switzerland]

March 1933	Relative numbers	March 1933	Relative numbers	March 1933	Relative numbers
1	10	11	7	21	0
2	10	12	7	22	d12
3	10	13	0	23	14
4	13	14	0	24	14
5	11	15	0	25	Mc24
6	a11	16	0	26	29
7	11	17	0	27	26
8		18	0	28	a28
9	9	19	0	29	22
10	8	20	0	30	d12
				31	10

Mean: 30 days=10.0.

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[Aerological Division, W. R. Gregg, in charge]

By L. T. SAMUELS

Free-air temperatures during March were above normal at all stations except Chicago and Cleveland. (See table 1.) The departures were only of moderate magnitude. Free-air relative humidities averaged above normal with departures of small to moderate magnitude in most cases.

There were no important deviations in the monthly resultant winds as compared to the normals.

TABLE 1.—*Free-air temperatures and relative humidities during March, 1933*

TEMPERATURE (° C.)

Altitude (meters) m.s.l.	Atlanta, Ga. (303 meters)[1]		Boston, Mass. (6 meters)[2]		Chicago, Ill. (187 meters)[3]		Cleveland, Ohio (246 meters)[3]		Dallas, Tex. (146 meters)[4]		Ellendale, N.Dak. (444 meters)		Omaha, Nebr. (300 meters)[5]		Pensacola, Fla. (2 meters)[6]		San Diego, Calif. (9 meters)[6]		Washington, D.C. (2 meters)[6]	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	7.5	(7)	0.9		0.2	(7)	−0.3	(7)	10.7	(7)	−2.6	−0.6	0.0	(7)	12.4	+0.9	13.5	−1.6	3.5	−2.0
500	7.9	(7)	−3.6		−0.5	(7)	−0.6	(7)	11.8	(7)	−2.7	−0.5	0.6	(7)	12.1	+1.7	12.0	−1.6	3.5	0
1,000	7.8	+1.3	−6.4		−2.5	−2.1	−3.1	−2.7	10.7	+2.0	−3.1	+0.4	1.0	+0.1	10.4	+1.9	11.5	−1.0	2.0	+0.5
1,500	6.4	+2.2	−7.3		−3.5	−1.6	−4.7	−2.8	9.8	+2.5	−3.8	+0.8	0.5	+0.2						
2,000	4.1	+2.1	−8.9		−5.1	−1.5	−6.6	−3.0	7.7	+2.0	−5.4	+1.0	−0.8	+0.6	6.0	+1.1	7.7	−0.2	−1.6	+1.2
2,500	1.6	+1.8	−11.0		−6.9	−1.1	−8.0	−2.2	5.3	+1.9	−7.5	+1.3	−2.8	+1.1						
3,000	−1.0	+1.4	−13.3		−9.2	−1.0	−10.1	−1.9	2.7	+1.8	−10.3	+1.3	−5.5	+1.0	1.0	+0.2	3.2	+0.8	−5.6	+1.2
4,000	−7.6	−0.3	−18.2		−14.1	−0.8	−15.9	−2.6	−3.3	+1.5	−15.1	+1.9	−12.0	−0.2	−4.7	+0.1	−4.6	+0.6		
5,000	−15.0	−1.6	−24.1		−20.5	−1.0	−22.5	−3.0	−10.5	+0.1	−22.6	+0.3	−18.8	−0.4	−11.1	+0.1				

RELATIVE HUMIDITY (PERCENT)

Altitude (meters) m.s.l.	Atlanta Mean	Atlanta Departure	Boston Mean	Boston Departure	Chicago Mean	Chicago Departure	Cleveland Mean	Cleveland Departure	Dallas Mean	Dallas Departure	Ellendale Mean	Ellendale Departure	Omaha Mean	Omaha Departure	Pensacola Mean	Pensacola Departure	San Diego Mean	San Diego Departure	Washington Mean	Washington Departure
Surface	76	(7)	64		79	(7)	81	(7)	77	(7)	73	0	82	(7)	76	+3	71	+4	73	+7
500	76	(7)	65		75	(7)	78	(7)	69	(7)	73	+1	75	(7)	67	+2	68	+3	65	+1
1,000	68	+9	65		71	+5	79	+13	63	+3	67	+3	62	+1	64	+5	54	0	62	0
1,500	63	+5	63		69	+10	71	+12	55	+4	57	−1	55	+3						
2,000	61	+7	63		65	+10	65	+10	49	+6	55	−1	50	0	60	+9	34	−4	57	−1
2,500	56	+6	63		61	+8	60	+7	43	+4	52	−4	50	0						
3,000	50	+6	62		60	+7	61	+8	39	+2	53	−4	51	0	56	+11	27	−4	54	+4
4,000	46	+6	57		55	+5	59	+9	36	−3	55	+2	48	−2	50	+10	26	−4		
5,000	45	−1	53		49	−5	58	+4	36	−3	57	+4	44	−6	53	+10				

Weather Bureau airplane observations made near 5 a.m.; Navy airplane observations near 7 a.m.; Ellendale kite observations near 9 a.m. (seventy-fifth meridian time).

[1] Temperature and humidity departures based on normals of Due West, S.C.
[2] Airplane observations made by Massachusetts Institute of Technology.
[3] Temperature and humidity departures based on normals of Royal Center, Ind.
[4] Temperature departures based on normals determined by interpolating between those of Groesbeck, Tex., and Broken Arrow, Okla. Humidity departures based on normals of Groesbeck, Tex.
[5] Temperature and humidity departures based on normals of Drexel, Nebr.
[6] Naval air stations.
[7] Surface and 500-meter level departures omitted because of difference in time of day between airplane observations and those of kites upon which the normals are based.

TABLE 2.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a.m. (E.S.T.) during March 1933*

[Wind from N=360°; E=90°, etc.]

Altitude (meters) m.s.l.	Albuquerque, N. Mex. (1,554 meters)		Atlanta, Ga. (309 meters)		Bismarck, N. Dak. (518 meters)		Brownsville, Tex. (12 meters)		Burlington, Vt. (132 meters)		Cheyenne, Wyo. (1,873 meters)		Chicago, Ill. (192 meters)		Cleveland, Ohio (245 meters)		Dallas, Tex. (154 meters)		Havre, Mont. (762 meters)		Jacksonville, Fla. (14 meters)		Key West, Fla. (11 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	330	2.3	295	2.1	64	1.4	145	2.0	290	0.2	306	4.9	338	1.1	284	1.7	144	0.8	257	1.4	311	1.0	79	2.0
500			314	3.8			156	4.9	308	3.8			278	3.5	284	2.9	203	3.2			298	1.8	101	4.8
1,000			287	5.7	202	2.8	179	3.0	303	4.1			296	7.0	297	5.4	244	3.9	255	4.1	254	3.4	133	2.9
1,500			288	9.4	267	2.4	266	3.2	303	7.6			291	7.7	293	7.0	243	5.8	273	7.3	262	5.7	183	2.2
2,000	293	3.2	291	11.2	291	4.6	315	5.1	312	11.5	301	6.9	288	10.7	290	9.6	275	8.1	273	7.9	275	7.4	239	2.3
2,500	290	6.0	290	10.8	294	5.9	304	4.7	318	14.1	298	10.9			293	12.6	277	9.1	273	10.3	278	8.5	275	3.4
3,000	280	8.0	291	9.9	289	7.8	295	7.3	320	10.6	292	11.3			302	15.6	273	8.4	277	11.0	280	9.0	293	4.6
4,000	273	12.3	302	15.7	296	8.1			315	9.0	275	10.9					283	8.6	273	11.9	278	12.1	292	7.4
5,000	269	14.5									260	12.3											295	7.9

Altitude (meters) m.s.l.	Los Angeles, Calif. (217 meters)		Medford, Oreg. (410 meters)		Memphis, Tenn. (83 meters)		New Orleans, La. (2 meters)		Oakland, Calif. (8 meters)		Oklahoma City, Okla. (402 meters)		Omaha, Nebr. (306 meters)		Phoenix, Ariz. (356 meters)		Salt Lake City, Utah (1,294 meters)		Sault Ste. Marie, Mich. (198 meters)		Seattle, Wash. (14 meters)		Washington, D.C. (10 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	24	0.4	90	0.1	174	0.8	74	1.0	234	0.4	205	1.0	95	1.3	88	1.5	154	1.3	25	1.5	150	2.3	290	2.4
500	27	0.8	273	.2	167	.9	108	1.5	269	1.8	200	2.2	135	1.8	71	.8			53	2.5	187	5.4	302	8.1
1,000	350	1.2	185	1.9	286	3.2	239	2.9	300	3.4	245	4.9	245	2.1	325	1.8			4	1.3	197	6.3	305	10.2
1,500	296	2.9	208	4.1	292	7.0	260	4.5	298	4.6	280	4.7	278	6.0	291	1.9	178	2.4	1	1.8	207	5.5	301	13.2
2,000	290	3.8	220	5.4	296	10.2	286	3.5	296	5.0	276	7.2	292	8.2	261	3.7	207	2.7	311	3.8	223	4.6	292	14.2
2,500	273	5.0	240	8.1	272	7.9	280	7.4	293	6.9	281	9.0	296	10.6	266	5.0	258	3.5	302	5.5	239	3.1	294	15.2
3,000	288	6.7	253	9.0			276	9.0	292	9.0	287	10.2	292	12.3	267	6.7	274	4.9	290	7.8	232	3.1	294	18.7
4,000	285	6.3	282	11.1					261	8.6	290	12.6	297	8.5	273	9.6	277	8.0	292	9.5	259	3.3		
5,000			271	13.2									309	9.8	283	12.6	284	8.6						

RIVERS AND FLOODS

By MONTROSE W. HAYES

[In charge River and Flood Division]

During March 1933 floods occurred in the Grand, St. Joseph, and Sandusky rivers in the St. Lawrence Basin; in the South Atlantic and East Gulf of Mexico States; in the Ohio Valley; and in Arkansas and Texas. Some of the floods had not begun to recede at the end of March, and information concerning the others is not complete. A discussion of them will, therefore, appear in a later issue of the REVIEW.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, W. F. McDonald in charge]

NORTH ATLANTIC OCEAN

By W. F. McDONALD

Atmospheric pressure.—Pressures during March 1933 averaged somewhat below normal over most of the North Atlantic but the deficiency was only one tenth to two tenths of an inch. A slight excess of pressure prevailed over the region between Spain and the Canary Islands. In West Indian waters the averages were about normal. (See table 1.)

The pressure observations reported from ships at sea ranged from 30.46 to 28.55 inches. The highest reported occurred on the 14th between the Azores and Madeira, when the normal area of high pressure in that region had its greatest development of the month, as indicated by chart VIII. The lowest was observed on the 21st near 54° N., 34° W., close to the center of the deep LOW shown on chart IX.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, March 1933*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.76		30.42	1	29.12	7
Reykjavik, Iceland	29.52	−0.02	30.20	1	28.81	7
Lerwick, Shetland Islands	29.75	+.05	30.29	21	29.01	17
Valencia, Ireland	29.76	−.14	30.46	27	28.82	17
Lisbon, Portugal	30.08	+.08	30.45	8	29.70	10
Madeira	30.13	+.12	30.30	15	29.87	22
Horta, Azores	30.06	−.12	30.40	14	29.58	1
Belle Isle, Newfoundland	29.79	−.01	30.32	27	28.82	11
Halifax, Nova Scotia	29.78	−.18	30.24	20	29.04	9
Nantucket	29.87	−.11	30.34	16	28.98	8
Hatteras	30.04	.00	30.44	16	29.42	8
Bermuda	30.04	−.10	30.28	13, 17	29.56	2
Turks Island	30.05	+.03	30.14	17	29.86	2
Key West	30.05	.00	30.20	5	29.72	20
New Orleans	30.05	+.01	30.28	5	29.48	19
Cape Gracias, Nicaragua	29.93		30.00	24	29.78	20

NOTE.—All data based on a.m. observations only with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans, which are 24-hour corrected means.

Cyclones and gales.—Gales were reported in March 1933 from an unusually large number of 5° squares in the North Atlantic but the storms were generally of less than average seasonal severity. Gales occurred in some parts of the ocean on all but 3 days of the month, and were reported south of the thirtieth parallel on 6 days. On many days, however, gales were quite local. Widespread storminess occurred in only a few brief periods, notably from the 1st to 3d, on the 7th and 8th; between the 16th and 20th, and on the 26th. Only a few gales exceeded force 10, the exceptions being as follows: force 11: off Nantucket on the 8th; near the Grand Banks on the 12th and 27th; in mid-ocean north of the 50th parallel on the 20th and 21st; and southwest of Ireland on the 17th. One ship, the Polish S.S. *Pulaski*, encountered on the 21st a wind estimated at force 12, in connection with the deepest storm of the month (as mentioned above and shown on chart IX).

During the first week, cyclonic conditions were dominant over the entire region between the east coast of the United States and western Europe. Later, however, slow-moving cyclones tended to pass at higher latitudes, and the normal belt of high pressure became established between the Azores and the West Indies. By the middle of the month, high pressures were well established between the twentieth and fortieth parallels, and cyclonic action had been crowded far northward towards Iceland and Greenland. This situation is illustrated on chart VIII. Thereafter, storminess increased somewhat, especially over the northeastern part of the ocean, culminating on the 20th and 21st in the deep low already referred to, and depicted on chart IX.

A succession of northern lows moved slowly eastward from the 21st until the close of the month. Occasionally during this period, trough-like extensions of cyclonic action disrupted the middle-latitude belt of high pressure, but in general the Atlantic HIGH was maintained with great stability after its establishment during the first half of the month.

Moderate gales on the 1st were reported from the Gulf of Mexico in connection with a mild "norther" that had its beginning at the end of February. There were southerly gales in that region on the 6th and 7th, in connection with a moderate disturbance that originated in the western part of the Gulf on the 5th.

The Caribbean trades.—The winds of the Caribbean region were somewhat weaker than usual, at no time exceeding force 6. Steadiness of direction also failed noticeably at times, and there was an unusual number of reports of southerly winds in the West Indies.

Fog.—Fog was observed on only 3 to 5 days over the western part of the main northern steamship routes, and on not more than 3 days between the Azores and the west coast of Europe. Fog frequency was much less than in February on the north coast of the Gulf of Mexico, but increased somewhat along the Atlantic coast from Chesapeake Bay southward to Jacksonville. A fog on the 29th was reported from midocean between Bermuda and the Azores, when fogs seldom occur.

OCEAN GALES AND STORMS, MARCH 1933

Vessel	Voyage: From—	Voyage: To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN			° ′	° ′				*Inches*					
Alabama, Am.S.S.	Key West	Port Arthur	25 43 N.	84 00 W.	Feb. 28	2 a., Mar. 1	Mar. 1		W	NNW., 6	NNE	N., 8	WNW.-NW.-NNW.
Black Tern, Am.S.S.	New York	Rotterdam	46 52 N.	37 35 W.	do	10 a., 1	do	29.06	E	NE., 9	N	ENE., 10	SE.-E.-NE.
Maja, Du.M.S.	Curacao	Lands End	44 01 N.	27 19 W.	Mar. 2	6—, 2	Mar. 2	29.02	SW	WSW., 9	NW	W., 10	SW.-WSW.-W.
Mopan, Br.S.S.	Port Talbot	Tela	29 08 N.	53 40 W.	do	2 a., 3	Mar. 3	29.93	SSE	SSW., 7	SW	S., 9	SSE.-S.-SW.
Beaconoil, Am.S.S.	Baytown, Tex.	Boston	41 20 N.	68 55 W.	do	do	Mar. 4	29.18	N	N., 9	N	N., 9	
Topa Topa, Am.S.S.	London	Mobile	47 52 N.	10 10 W.	do	—, 3	Mar. 6	29.04	SE	SW., 8	W	SW., 10	SW.-NW.
Chester Sun, Am.S.S.	Marcus Hook	Texas ports	28 23 N.	90 10 W.	Mar. 5	2 p., 7	Mar. 8	29.72	NE	W., 8	NW	W., 8	S.-SW.-W.
West Madaket, Am.S.S.	Manchester	Pensacola	28 30 N.	85 45 W.	Mar. 6	9 p., 6	Mar. 7	29.74	SSE	SE., 8	W	SSE., 8	SSE.-W.
San Pedro, Fr.S.S.	Antwerp	New Orleans	32 48 N.	52 12 W.	do	7 p., 6	do	29.64	W	W., 10	NW	W., 10	WNW.-NW.
Shenandoah, Am.S.S.	Port Arthur	Thameshaven	38 00 N.	69 00 W.	Mar. 7	6 a., 8	Mar. 9	29.09	SSE	W., 3	W	SSE., 11	W.-WSW.
Cubano, Nor.S.S.	New York	Brazil	39 55 N.	73 00 W.	Mar. 8	6 p., 8	Mar. 10	[1] 29.25	SW	WSW., 5	W	W., 10	WSW.-SW.
City of Dalhart, Am.S.S.	do	Port Said	42 24 N.	43 58 W.	Mar. 9	8 p., 9	Mar. 9	29.75	S	SSW., 9	SW	SSW., 10	SSW.-S.-SW.
Dresden, Ger.S.S.	do	Queenstown	41 22 N.	62 31 W.	Mar. 11	4 a., 11	Mar. 11	[1] 29.68	W	W., 9	W	W., 10	
Bremen, Ger.S.S.	Bremerhaven	New York	44 56 N.	44 40 W.	do	3 p., 11	Mar. 12	29.24	WSW	WSW., 8	W	WSW., 11	
Caledonia, Br.S.S.	Glasgow	do	51 14 N.	31 52 W.	Mar. 14	4 p., 14	Mar. 17	29.23	W	W., 7	W	W., 9	W.-NW.-W.
Persier, Belg.S.S.	South America.	Antwerp	15 17 N.	26 12 W.	do	do	Mar. 16	[1] 29.70	NNE	NNE., 7	NE	NNE., 9	NNE.-ENE.-NNE.
Norwegian, Br.S.S.	Liverpool	Boston	52 54 N.	25 15 W.	Mar. 15	8 a., 15	do	29.08	WSW	WSW., 10	NW	WSW., 10	Steady.
Dresden, Ger.S.S.	New York	Queenstown	51 01 N.	13 41 W.	Mar. 16	4—, 17	Mar. 17	[1] 28.80	W	W., 5	NW	do	
Black Falcon, Am.S.S.	do	Rotterdam	49 07 N.	22 20 W.	do	11 p., 18	Mar. 20	29.23	SW	W., 8	NW	WNW., 9	SW.-W.-NW.
Steelmaker, Am.S.S.	Swansea	St. John, N.B.	51 27 N.	18 30 W.	do	7 p., 16	Mar. 17	28.76	S	SW., 7	NW	SW., 9	SW.-W.-WNW.
Lubrafol, Belg.M.S.	Antwerp	Galveston	45 36 N.	16 59 W.	do	2 p., 16	do	[1] 29.37	SW	SW., 9	W	NW., 9	SW.-W.-NW.
Elmsport, Am.S.S.	New Orleans	Liverpool	48 50 N.	28 10 W.	Mar. 17	4 a., 20	Mar. 20	29.20	WNW	S., 8	SW	S., 8	W.-S.-SSW.
Boschdijk, Du.S.S.	Rotterdam	New York	45 58 N.	41 49 W.	do	12 p., 18	Mar. 18	29.56	W	W., 9	W	W., 9	Steady.
Weirbank, Br.S.S.	Port Said	Halifax	42 00 N.	36 15 W.	do	4 p., 19	Mar. 21	[1] 29.14	WSW	SSW., 10	WNW	WNW., 10	SSW.-W.-WNW.
Black Tern, Am.S.S.	Rotterdam	New York	45 46 N.	40 22 W.	do	2 a., 20	do	28.98	W	W., 10	NW	W., 10	W.-WSW.-NW.
Champlain, Fr.S.S.	New York	Plymouth	49 40 N.	12 41 W.	do	11 a., 17	Mar. 18	29.98	WNW	WNW., 11	WNW	WNW., 11	Steady.
Europa, Ger.S.S.	do	English Channel and return.	49 52 N.	11 18 W.	do	8 a., 17	Mar. 19	28.88	W	W., 8	NW	WSW., 11	
Paris, Fr.S.S.	Havre	New York	47 03 N.	35 28 W.	Mar. 18	—, 18	Mar. 18	29.18	WNW	WNW		W., 10	WNW.-W.-WNW.
Norwegian, Br.S.S.	Liverpool	Boston	46 41 N.	43 15 W.	Mar. 19	12 p., 19	Mar. 20	28.91	NW	NW., 7	NW	NW., 9	SW.-NW.
Steelmaker, Am.S.S.	Swansea	St. John, N.B	51 02 N.	37 17 W.	do	2 p., 20	Mar. 21	28.55	ESE	ENE., 6	NW	NW., 11	SSW.-E.-NE.
Adria, Ger.S.S.	Bordeaux	Venezuela	35 03 N.	37 06 W.	do	8 a., 20	do	[1] 29.65	SW	SW., 8	N	WSW., 8	
Berlin, Ger.S.S.	New York	English Channel.	46 48 N.	37 34 W.	do	4 a., 21	Mar. 22	29.28	W	WNW., 9	WNW	WNW., 9	Steady.
Mopan, Br.S.S.	Tela	Rotterdam	42 50 N.	45 07 W.	Mar. 20	5 a., 20	Mar. 21	[1] 29.36	WNW	do	NW	do	WNW.-NW.
Tennessee, Dan.S.S.	Harburg	Norfolk	49 40 N.	24 20 W.	do	11 a., 24	Mar. 29	29.15	S	W., 5	WNW	S., 11	S.-SW.-WNW.
Veendam, Du.S.S.	Rotterdam	New York	49 06 N.	37 01 W.	do	—, 23	Mar. 24	29.02	S	WSW., 8	NNW	WSW., 9	SSW.-W.-NW.
Barbara, Am.S.S.	San Juan	Philadelphia	23 49 N.	72 31 W.	Mar. 21	2 p., 21	Mar. 22	29.52	SSW	WSW., 7	W	WSW., 8	SSW.-WSW.
Pulaski, Pol.S.S.	Gdynia, Poland.	New York	54 41 N.	34 50 W.	do	12 m., 21	do	28.55	NNW	NNW., 7	NW	NNW., 12	E.-NE.-NNW.
Yomachichi, Am.M.S.	Gibraltar	do	37 25 N.	62 00 W.	do	2 a., 22	Mar. 23	29.58	SW	SSE., 9	NW	WNW., 10	WNW.-NW.
Champlain, Fr.S.S.	Plymouth	do	49 32 N.	22 50 W.	Mar. 24	3 p., 24	Mar. 24	29.40	SSE	S., 9	WNW	S., 9	SSE.-W.-WNW.
Steelmaker, Am.S.S.	Swansea	St. John	43 14 N.	64 28 W.	Mar. 26	3 p., 27	Mar. 28	29.61	E	NNE., 9	N	NNE., 10	NE.-NNE.
Bremen, Ger.S.S.	Bremerhaven	New York	43 30 N.	52 45 W.	Mar. 27	11 p., 27	do	29.25	ESE	ESE., 11	W	ESE., 11	SE.-S.-W.
Maria, Ital.M.S.	Lisbon	do	39 27 N.	55 48 W.	do	1 a., 28		29.96	S	SW., 8		SW., 9	
Independence Hall, Am. S.S.	Havre	do	41 44 N.	59 18 W.	Mar. 30	6 p., 30		29.70	NW	NW., 7		NW., 8	NW.-NNW.-NW.
NORTH PACIFIC OCEAN													
Pres. Cleveland, Am.S.S.	Victoria	Yokohama	45 03 N.	155 21 E.	Feb. 26	Mar. 2	Mar. 2	29.33	S	SW., 9	S	SW., 10	
Ogura Maru, Jap.M.S.	San Francisco	do	34 28 N.	147 48 E.	Feb. 28	12 p., 1	do	29.43	SE	NE., 9	NNW	NNE., 10	NE.-NNE.-N.
Golden Peak, Am.S.S.	Portland	do	42 57 N.	155 42 E.	Mar. 2	2 p., 2	Mar. 3	29.28	N	N., 9	W	N., 9	4 points.
Gen. Pershing, Am.S.S.	do	do	42 00 N.	138 38 W.	Mar. 3	4 p., 3	Mar. 4	29.54	SSE		S	S., 9	Steady.
Kota Inten, Du.M.S.	Manila	Portland	45 35 N.	168 25 E.	Mar. 7	5 a., 8	Mar. 8	29.55	S	S., 7	W	S., 8	
Do	do	do	49 40 N.	177 00 W.	Mar. 9	4 p., 9	Mar. 9	29.46	NE	SE., 10	SSE	ESE., 11	
Atago Maru, Jap.M.S.	Yokohama	San Francisco	44 55 N.	142 37 W.	Mar. 7	6 a., 8	do	29.47	ESE	ESE., 9	NE	ESE., 9	ESE.-SE.
Pulpit Point, Br.S.S.	Itosaki	do	38 55 N.	157 00 E.	Mar. 8	4 a., 9	do	29.16	E	NE., 10	WNW	NE., 10	E.-NE.-N.
Kiyo Maru, Jap.S.S.	Yokohama	Los Angeles	43 43 N.	156 20 W.	do	2 a., 9	do	29.38	NNW	NNW., 6	NE	NNW., 8	WNW.-NE.
Golden Dragon, Am.S.S.			51 00 N.	173 12 W.	Mar. 9	4 a., 10	Mar. 10	29.77	SSE		SW	SSE., 9	Steady.
New York, Am.S.S.	Portland	Shanghai	48 10 N.	167 26 E.	do	1 p., 9	Mar. 11	28.91	NE		W	WNW., 10	
Shelton, Am.S.S.	Legaspi	Los Angeles	38 43 N.	173 74 E.	do	6 p., 9	Mar. 15	29.53	SSW	SSW., 8	W	W., 10	W.-WNW.
Badjestan, Br.S.S.	Vancouver	Panama	42 36 N.	125 32 W.	Mar. 10	4 p., 11	Mar. 11	29.64	S	S., 8	SSW	S., 9	Steady.
Koyo Maru, Jap.S.S.	Yokohama	Port San Luis	40 44 N.	153 23 W.	Mar. 12	4 p., 12	Mar. 13	29.67	NW	NW., 8	NW	NW., 8	Do.
Shelton, Am.S.S.	Legaspi	Los Angeles	41 43 N.	158 20 E.	do	6 a., 14	Mar. 15	29.47	SW	WNW	SW	W., 10	WNW.-W.
Kota Inten, Du.M.S.	Manila	Portland	49 10 N.	135 30 W.	Mar. 14	2 a., 15	do	28.92	SSE	SE., 8	N	SE., 8	
Hakutatsu Maru, Jap. S.S.	Shiogama	Seattle	46 44 N.	161 35 E.	do	12 m., 15	do	29.56	E	ENE., 9	NNE	E., 9	E.-NE.
San Luis Maru, Jap.M.S.	Yokohama	Port San Luis	40 58 N.	154 47 E.	do	4 p., 14	do	29.11	NE	NW., 9	SW	W., 10	N.-NW.-W.
Shoyo Maru, Jap.S.S.	Los Angeles	Hakodate	40 50 N.	161 09 E.	do	8 p., 15	Mar. 16	28.86	E	WSW., 7	NNW	WSW., 9	SW.-WSW.
Carlier, Belg.S.S.	Balboa	Grays Harbor	42 16 N.	125 06 W.	Mar. 15	3 p., 15	Mar. 15	29.61	SSE	SSE., 9	SSW	SSE., 9	SE.-SSE.
Fernwood, Nor.M.S.	San Pedro	Yokohama	35 00 N.	165 00 E.	do	3 a., 15	do	29.48	W	W., 9	WNW	W., 9	W.-WNW.
Do	do	do	34 50 N.	154 30 E.	Mar. 17	8 p., 17	Mar. 17	29.60	S	S., 9	W	SW., 10	S.-SW.-W.
Gen. Pershing, Am.S.S.			34 38 N.	168 40 E.	Mar. 16	10 p., 16	Mar. 16	29.63	WNW		WNW	W., 10	
New York, Am.S.S.	Portland	Shanghai	42 35 N.	145 33 E.	Mar. 17	8 p., 17	Mar. 17	29.20	ENE		NNW	NNE., 11	
Shoyo Maru, Jap.S.S.	Los Angeles	Hakodate	41 10 N.	152 36 E.	do	do		29.03	ESE	W., 11			
Golden River, Am.S.S.	Yokohama	San Francisco	41 30 N.	153 05 E.	do	9 p., 17	Mar. 20	29.04	SE	SE., 12	WSW	WSW., 12	SE.-SW.
Texas, Am.S.S.	Vladivostok	do	41 50 N.	175 00 E.	Mar. 18	12 p., 18	Mar. 18	29.36	SE	SE., 10	W	SE., 10	SE.-W.
Emp. of Russia, Br.S.S.	Vancouver	Yokohama	47 20 N.	162 46 E.	Mar. 19	11 a., 19	Mar. 20	28.75	S	SSW., 9	W	W., 10	Steady.
Do	do	do	41 40 N.	150 53 E.	Mar. 21	2 a., 22	Mar. 22	29.20	E	NNE., 10	N	N., 11	Do.
General Lee, Am.S.S.	Yokohama	San Francisco	35 35 N.	143 04 E.	Mar. 22	4 a., 22	do	29.38	WNW	NW., 7	NNW	WNW., 10	
San Diego Maru, Jap. M.S.	do	do	41 59 N.	155 52 E.	Mar. 21	—, 22	Mar. 23	28.97	SE	ENE., 8	NW	N., 10	E.-ENE.-NE.
San Pedro Maru, Jap. M.S.	Osaka	do	40 24 N.	161 33 E.	do	8 p., 22	Mar. 24	28.98	SE	NE., 5	W	NW., 10	10 points.
Hakutatsu Maru, Jap. S.S.	Shiogama	Seattle	50 10 N.	154 00 W.	Mar. 22	12 m., 22	Mar. 23	29.64		S., 11	W	SW., 11	S.-SSW.
Golden River, Am.S.S.	Yokohama	San Francisco	47 30 N.	169 42 W.	Mar. 23	10 a., 23	do	29.47	SE	SE., 9	S	SE., 9	SE.-S.
Saparoea, Du.M.S.	Manila	San Pedro	36 32 N.	163 40 E.	Mar. 24	5 p., 25	Mar. 25	29.57	SSW	SSW., 9	NW	SSW., 9	
Hakutatsu Maru, Jap. S.S.	Shiogama	Seattle	48 57 N.	128 07 W.	Mar. 26	2a., 27		29.78	E	SE		SE., 8	E.-SE.
San Diego Maru, Jap. M.S.	Yokohama	San Francisco	46 03 N.	173 00 W.	Mar. 27	4 p., 27	Mar. 28	28.75	S	SSW., 4	WNW	NW., 12	SSW.-NW.

[1] Barometer uncorrected.

NORTH PACIFIC OCEAN, MARCH 1933

By WILLIS E. HURD

Atmospheric pressure.—Pressure during March 1933 was lower than in the preceding month over the Aleutian region and along the entire American Pacific coast, but was higher than in February at Honolulu and Midway Island. No departures for the month exceeded 0.10 inch, however, in any part of the North Pacific.

The Aleutian cyclone was central east of the Peninsula of Alaska (Kodiak, 29.64 inches). Of the various fluctuating LOWS composing it, the greatest depths were attained generally near the middle and toward the end of the month. The Pacific anticyclone extended across the ocean in middle latitudes, with the crest lying between the one hundred and eightieth meridian and the California coast.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, March 1933, at selected stations*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow	30.12	−0.03	30.78	1	29.24	16
Dutch Harbor	29.73	+.03	30.56	9	28.68	30, 31
St. Paul	29.75	+.02	30.60	9	28.90	30, 31
Kodiak	29.64	−.05	30.68	8	28.74	29
Juneau	29.84	−.10	30.57	8	29.09	29
Tatoosh Island	29.97	+.01	30.52	4	29.31	11
San Francisco	30.10	+.04	30.36	3	29.84	11
Mazatlan	29.91	−.09	30.02	24	29.82	15, 21
Honolulu	30.07	+.03	30.22	18	29.72	3
Midway Island	30.10	+.03	30.26	28, 29	29.80	2
Guam	29.84	−.06	29.92	29	29.78	15
Manila	29.87	−.08	29.96	29	29.80	24, 25
Naha	30.03	+.03	30.26	13	29.72	26
Chichishima	30.00	.00	30.22	29	29.70	25
Nemuro	29.95	-------	30.32	9	29.36	17

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

Cyclones and gales.—March as a whole was much stormier over the North Pacific than February, particularly over the western part of the northern and middle routes lying roughly between the central Aleutians and the Japanese Islands. In that region 20 to 30 percent of the days in March had gales, the majority of which were of force 10. East of northern Japan there were, in addition, gales of force 11 in a few localities on the 19th and 22d, and a considerable region was swept by gales of forces 11–12 on the 17th. East of the Kuril Islands snowstorms were frequent and heavy, and mostly accompanied by gales, from the 9th to the 22d.

The American steamer *New York*, westbound, reported thick snow and high winds for 18 hours on the 9th and 10th, near 49°–48° N., 168° to 167° E.; 38 hours on the 14th and 15th, near 45° N., 157° to 152° E.; 11 hours on the 17th, near 43° N., 145° to 143° E.; and several hours on other days between the 11th and 18th.

East of the one hundred and eightieth meridian gales decreased in number, and for the most part also in intensity, toward the American coast, forces 8 and 9 constituting the major portion. The exceptions were winds of forces 11–12 south of the central Aleutians on the 9th and 27th; near 50° N., 155° W. on the 22d; and southeast of Dutch Harbor on the 23d. Whereas in February the region south and southeast of the Peninsula of Alaska was the stormiest of that month, in March, except on the 22d and 23d, it seems to have been freer than usual of winter gales.

Off the coast of northern California and Oregon gales of force 8–9 were reported on the 10th and 14th.

Northers and monsoons.—A moderate norther occurred in the Gulf of Tehuantepec on the 1st. Northeast monsoons of fresh gale force were reported in the Taiwan Channel and thence northward for some distance along the China coast on the 5th to 7th.

Fog.—March was the first month since September 1932 during which an appreciable amount of fog formed along the northern routes from midocean westward. Extended fog masses occurred between 170° W. and 160° E. from the 5th to 9th. In the neighborhood of Midway Island fog was encountered on the 26th to 28th. Scattered fogs were observed over the northeastern quarter of the ocean. Along the American coast fog was reported on 11 days off the entire length of the United States, and on 5 days off Lower California.

CLIMATOLOGICAL TABLES [1]

CONDENSED CLIMATOLOGICAL SUMMARY

Compiled by Annie E. Small

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, March 1933

[For description of tables and charts, see Review, January, p. 37]

Section	Temperature								Precipitation					
			Monthly extremes								Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	56.0	+0.3	Pushmataha	87	16	3 stations	24	[1]3	6.88	+0.98	Citronelle	13.64	Cordova	3.15
Arizona	53.7	+.6	Parker	97	29	Bright Angel	8		.01	−1.02	2 stations	.16	90 stations	.00
Arkansas	52.6	+.2	Rison	91	14	Sunset	17	21	4.87	+.20	Jonesboro	8.37	Fayetteville	1.90
California	50.1	−1.3	Blythe	98	31	Twin Lakes	−6	24	2.65	−1.00	Upper Mattole	24.40	21 stations	.00
Colorado	37.4	+3.1	Holly	85	[1]12	Fraser	−20	10	.91	−.41	Willow Creek	4.06	2 stations	.00
Florida	65.0	−.5	Bartow	91	15	Glen St. Mary	30	4	3.72	+.58	Panama City	7.66	Davie	1.11
Georgia	56.4	+.1	Millen	89	[1]18	Blairsville	15	4	3.49	−1.39	Blakely	7.35	Savannah	.91
Idaho	35.6	−1.8	Emmett	72	27	4 stations	−14	[1]5	1.14	−.60	Roland	4.24	Salmon	.03
Illinois	40.7	+.8	Hardin	89	13	3 stations	2	10	4.12	+1.06	Newton	7.88	Rochelle	.39
Indiana	40.1	−.4	Rome	82	14	2 stations	5	10	5.41	+1.66	Vevay (near)	9.43	Notre Dame	2.94
Iowa	36.0	+1.7	2 stations	77	13	do	−3	10	3.09	+1.34	Grundy Center	6.58	Lamoni	1.36
Kansas	46.1	+3.1	do	86	[1]12	Leoti	5	20	1.47	.00	Lawrence	4.08	Plains	.00
Kentucky	46.0	−.1	5 stations	78	[1]13	Irvington	10	10	5.52	+.90	Cold Spring	10.05	Burnside	2.57
Louisiana	61.7	+1.2	Schriever	89	[1]30	Calhoun	27	21	5.83	+1.11	Houma	10.28	Calhoun	3.37
Maryland-Delaware	40.3	−2.7	Millsboro, Del	80	14	Sines, Md	0	11	4.28	+.84	Grantsville, Md	7.83	Salisbury, Md	1.48
Michigan	29.4	−.2	Eau Claire	68	31	Wolverine	−20	11	1.83	−.34	Mackinac Island	3.40	Seney	.73
Minnesota	27.2	+.9	Canby	70	12	Big Falls	−30	9	1.33	+.14	Worthington	3.71	Sandy Lake Dam	.13
Mississippi	57.6	+.9	2 stations	89	[1]14	3 stations	26	[1]4	6.75	+.99	Water Valley	12.05	Columbus	3.89
Missouri	44.1	+.5	Warsaw	87	13	Unionville	5	10	3.53	+.38	Caruthersville	10.39	Caplinger Mills	1.56
Montana	34.5	+3.8	Ballantine	79	28	Hebgen Dam	−23	5	.52	−.42	Heron	3.70	3 stations	T
Nebraska	38.7	+2.8	Benkelman	90	29	Mullen	−5	10	2.06	+.96	Purdum	5.20	Kowanda	.37
Nevada	42.0	+1.8	Logandale	88	27	Owyhee	−5	4	.43	−.56	Marlette Lake	4.78	3 stations	.00
New England	30.6	−1.6	Stockbridge, Mass	64	17	Van Buren, Me	−25	14	4.79	+1.47	Pawtucket, R.I.	7.91	Eastport, Me.	1.46
New Jersey	38.2	−.4	Belleplain	70	14	Culvers Lake	8	11	4.49	+1.05	Belvidere	6.34	Port Norris	2.59
New Mexico	45.3	+1.6	Carlsbad	90	[1]8	2 stations	−8	5	.16	−.60	Rencona (near)	1.43	42 stations	.00
New York	31.2	−.8	3 stations	68	[1]14	Stillwater Reservoir	−21	11	3.78	+.73	New York City	5.89	Letchworth Park	1.34
North Carolina	49.7	−.1	Goldsboro	87	19	Mount Mitchell	6	10	2.70	−1.47	Tapoco	6.85	Manteo	1.02
North Dakota	28.5	+4.4	3 stations	70	[1]28	3 stations	−14	9	.45	−.25	Hankinson	1.50	Berthold Agency	T
Ohio	38.4	−.2	Ironton	78	14	Hiram	3	11	5.54	+2.16	Wilmington	10.87	Montpelier	2.25
Oklahoma	52.9	+2.5	2 stations	88	[1]13	Goodwell	14	20	2.38	+.21	Hugo	5.88	Buffalo	.04
Oregon	40.2	−.7	do	73	19	Sheaville	−9	5	3.09	+.33	Tillamook	18.32	Andrews	.23
Pennsylvania	36.6	−1.1	Hyndman	79	14	Kane (near)	−7	11	5.33	+1.89	Elk Lick	8.95	Erie	2.74
South Carolina	54.3	−.3	Garnett	89	19	3 stations	19	[1]3	1.96	−1.94	Ceasar's Head	4.56	Marion	.76
South Dakota	34.2	+3.5	Armour	80	29	De Smet	−16	9	1.62	+.50	Belvidere	4.59	Britton	.41
Tennessee	49.4	+.2	2 stations	83	14	3 stations	16	[1]1	5.65	+.34	Selmer	11.22	Elizabethton	1.87
Texas	60.6	+1.9	do	100	[1]13	Spearman	15	20	1.89	−.19	Marshall	7.38	15 stations	.00
Utah	37.8	−.4	St. George	81	[1]27	Woodruff	−14	5	.82	−.61	Silver Lake	3.49	2 stations	T
Virginia	44.6	−1.4	2 stations	84	14	Glenlyn	9	11	3.12	−.56	Monterey	6.24	Langley Field	1.39
Washington	41.4	−1.1	Lowden	70	17	Bumping Lake	−1	3	4.73	+1.42	Naselle	21.54	Hanford	.43
West Virginia	40.5	−1.8	Charleston	80	20	Pickens	−4	11	5.92	+2.05	Pickens	11.59	Upper Tract	1.59
Wisconsin	28.5	−.8	2 stations	65	[1]12	Rest Lake	−20	10	2.04	+.25	Grand River Locks	4.60	Merrill	.44
Wyoming	32.1	+2.5	Pinebluff	77	28	Riverside	−29	5	.95	−.23	Dome Lake	4.66	Dubois	.03
Alaska [February]	6.8	−2.4	2 stations	49	[1]10	Fort Yukon	−59	[1]1	1.64	−.28	View Cove	9.97	Kasilof	T
Hawaii	68.7	−.2	Napoopoo	89	7	Kanalohuluhulu	39	16	10.81	+1.77	Puohakamoa no. 2	34.40	Olowalu	.55
Puerto Rico	74.4	+.3	Dorado	92	4	Guineo Reservoir	43	1	6.40	+2.92	Mayaguez	23.85	Aguirre	.71

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, March 1933*

[Compiled by Annie E. Small]

District and station	Elevation of instruments: Barometer above sea level	Elevation: Thermometer above ground	Elevation: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							32.9	+0.2										72	4.98	+1.5										6.2		
Eastport	76	67	85	29.77	29.86	-0.07	29.2	+0.3	45	31	36	5	11	23	26	26	22	76	1.46	-2.4	13	11,072	nw.	46	e.	8	8	6	17	6.4	4.1	0.0
Greenville, Me.	1,070	6		28.67	29.89		22.4		46	31	32	-6	11	12	41				4.35		11	6,018	nw.	28		11	9	9	13		29.0	
Portland, Me.	103	82	117	29.77	29.89	-.07	32.6	+.8	54	17	39	8	11	26	28	28	22	67	5.94	+2.1	9	8,996	nw.	34	nw.	5	13	7	11	4.9	9.2	.0
Concord	289	70	79	29.58	29.90	-.10	31.1	+.3	55	17	38	5	11	24	35				5.23	+2.2	12	6,343	nw.	27	w.	9	15	5	11	4.6	13.9	.0
Burlington	403	11	48	29.48	29.94	-.06	26.5	-2.6	47	31	34	2	6	20	27				2.92	+.9	12	6,572	n.	30	sw.	9	9	2	20	7.1	11.8	T
Northfield	876	12	60		29.94	-.06	25.2	-1.2	46	31	34	0	11	16	34			81	2.29	-.3	11	6,291	n.	28	sw.	9	4	10	17	7.4	13.7	8.0
Boston	125	106	165	29.76	29.90	-.07	35.7	+.1	60	17	42	11	11	30	26	31	24	65	6.80	+3.2	14	7,890	nw.	26	w.	9	11	7	13	6.0	5.1	.0
Nantucket	12	14	90	29.86	29.87	-.11	36.8	+1.3	53	21	42	16	11	32	18	34	29	77	7.34	+3.6	15	13,228	w.	45	ne.	26	9	8	14	6.4	9.0	.0
Block Island	26	11	46	29.87	29.90	-.08	36.4	+1.0	52	8	42	13	11	31	18	34	30	80	4.95	+1.1	14	15,417	w.	47	nw.	10	7	11	13	6.2	3.5	.0
Providence	160	215	251	29.72	29.90	-.08	35.7	.0	55	17	42	12	11	30	24	31	24	64	5.70	+2.2	15	10,736	nw.	50	nw.	10	12	4	15	5.7	6.9	.0
Hartford	159	122		29.77	29.96	-.03	36.1	+1.1	55	17	43	10	11	30	25				5.56	+1.7	14		nw.				8	7	16	6.4	5.3	.0
New Haven	106	74	153	29.82	29.94	-.05	36.7	+.9	55	17	43	11	11	31	21	32	26	68	6.60	+2.5	13	8,399	nw.	32	sw.	9	8	7	16	7.1	5.8	.0
Middle Atlantic States							41.0	+.2										67	3.84	+.4										6.7		
Albany	97	107	115	29.85	29.96	-.05	33.0	+.3	57	17	39	8	11	27	26	29	24	70	4.02	+1.4	16	6,249	n.	22	w.	10	7	6	18	7.1	7.6	.0
Binghamton	871	60	68	28.99	29.94	-.08	33.6	+1.0	66	14	40	10	11	27	30				3.17	+.6	17	5,882	nw.	25	nw.	9	3	4	24	8.5	6.9	.0
New York	314	414	454	29.59	29.94	-.06	38.0	+.3	57	17	44	15	11	32	23	33	27	68	5.89	+2.2	14	13,509	nw.	50	nw.	9	6	10	15	6.9	3.1	.0
Bellefonte	1,050	5	42	28.83	29.97		36.2		71	14	46	10	11	27	34	31	26	75	4.33		14		w.	36	w.	9	3	7	21	8.0	2.5	.0
Harrisburg	374	94	104	29.57	29.98	-.05	38.7	-.2	63	17	45	17	11	32	28	33	26	64	5.65	+2.6	14	7,275	nw.	37	nw.	8	5	10	16	6.8	4.1	.0
Philadelphia	114	123	367	29.86	29.98	-.04	41.4	+.6	60	17	48	20	11	35	24	35	27	62	4.86	+1.5	12	11,361	nw.	39	w.	9	6	6	19	6.9	.7	.0
Reading	323	283	304	29.62	29.98		39.7	-.3	67	17	47	16	11	32	31	34	26	65	4.46	+.9	13	11,421	nw.	50	w.	9	5	11	15	6.6	4.0	.0
Scranton	805	72	103	29.09	29.97	-.05	35.2	-.5	66	14	42	12	11	29	30	32	27	74	3.53	+.3	16	6,442	nw.	25	nw.	10	4	9	18	7.4	5.0	.0
Atlantic City	52	37	172	29.90	29.96	-.06	41.0	+2.4	61	15	46	18	11	34	26	36	30	76	3.44	-.2	15	13,117	nw.	47	w.	9	8	6	17	6.7	T	.0
Sandy Hook	22	10	55	29.92	29.94		38.2		56	17	43	18	11	33	22	35	30	76	4.79	+.8	16	12,806	nw.	41	nw.	10	8	9	14	6.2	.5	.0
Trenton	190	159	183	29.76	29.97		38.6	-.5	59	17	45	17	11	32	26	34	28	70	5.59	+2.2	15	8,504	nw.	34	w.	9	6	9	16	6.6	3.2	.0
Baltimore	123	100	215	29.85	29.99	-.04	42.8	+.5	76	14	50	20	11	36	32	37	29	62	4.60	+.9	11	9,405	nw.	40	sw.	9	8	7	16	6.5	2.5	.0
Washington	112	62	85	29.87	30.00	-.04	43.0	+.4	74	14	51	20	11	35	29	36	28	65	3.24	-.5	13	6,761	nw.	32	nw.	15	11	5	15	6.1	1.0	.0
Cape Henry	18	8	54	29.98	30.00		48.2	+1.6	83	14	56	27	11	40	31	42	36	69	2.10	-1.7	11	10,956	nw.	40	n.	29	7	16	8	5.8	T	.0
Lynchburg	681	153	188	29.25	30.01	-.04	46.4	-.9	73	18	56	21	11	37	36	38	30	58	2.72	-.8	8	6,528	nw.	30	nw.	10	13	9	9	5.2	T	.0
Norfolk	91	170	205	29.92	30.02	-.01	49.0	+.8	79	14	58	24	11	40	31	41	35	66	1.98	-1.8	11	11,046	nw.	42	w.	8	5	10	16	6.6	.0	.0
Richmond	144	11	52	29.86	30.02	-.02	46.4	-.8	78	14	56	20	11	37	33	39	32	64	2.15	-1.5	10	7,764	n.	36	w.	12	9	10	12	5.7	T	.0
Wytheville	2,304	49	55	27.60	30.03	-.02	41.6	-.7	71	18	51	18	11	32	35	36	30	66	3.12	-.3	10	7,179	w.	32	w.	23	8	9	14	6.3	1.1	.0
South Atlantic States							54.8	+1.1										65	2.21	-1.5										4.1		
Asheville	2,253	89	104	27.66	30.05	-.01	46.4	+1.5	79	18	58	22	6	35	41	40	36	75	2.29	-1.7	11	8,421	nw.	34	e.	7	10	12	9	5.2	T	.0
Charlotte	779	244	267	29.20	30.04	-.01	51.2	+.8	78	18	61	28	11	42	29	44	36	59	2.52	-1.6	10	10,255	sw.	43	se.	7	11	13	7	4.4	.0	.0
Greensboro	886	6	56	29.07	30.04		46.8		77	18	59	21	11	35	39	40	33	65	2.50		9	7,695	sw.	35	sw.	7	10	13	8	5.0	T	.0
Hatteras	11	5	50	30.02	30.03	-.01	52.6	+.6	72	19	60	34	6	46	22	48	44	75	2.63	-1.6	8	11,078	sw.	37	se.	7	13	12	6	4.1	.0	.0
Raleigh	376	103	146	29.62	30.04	-.01	51.5	+1.3	83	19	62	25	11	41	33	43	33	54	2.01	-1.9	9	8,146	sw.	32	nw.	8	14	8	9	4.6	T	.0
Wilmington	72	73	106	29.99	30.06	+.01	54.8	+1.5	81	15	64	31	11	45	27	47	40	66	2.88	-.3	6	8,696	nw.	28	sw.	13	15	13	3	3.5	.0	.0
Charleston	48	11	92	30.02	30.07	+.01	58.2	+.8	83	15	66	36	3	50	26	51	45	68	.99	-2.0	2	8,891	sw.	35	s.	20	17	9	5	3.7	.0	.0
Columbia, S.C	351	41	57	29.67	30.06	.00	55.8	+.6	84	19	67	29	5	45	31	47	40	62	2.35	-1.1	5	6,769	sw.	31	sw.	7	15	12	4	3.8	.0	.0
Greenville, S.C	1,039	139	146	28.93	30.03		52.4	+2.5	77	18	62	30	5	42	33	44	36	60	2.23	-2.9	10	7,895	sw.	38	w.	23	16	6	9	4.2	.0	.0
Augusta	182	62	77	29.86	30.05	-.01	57.6	+1.6	85	19	69	32	4	46	33	48	41	60	2.57	-1.5	6	5,888	nw.	27	w.	7	14	11	6	4.1	.0	.0
Savannah	65	73	152	30.00	30.07	+.01	60.1	+1.1	82	15	70	36	3	50	31	51	46	70	.91	-2.2	4	9,116	s.	38	s.	20	17	8	6	3.2	.0	.0
Jacksonville	43	209	245	30.03	30.08	+.02	62.4	-.2	84	18	71	38	4	54	26	54	48	68	2.97	+.1	9	9,132	w.	35	sw.	20	16	10	5	3.6	.0	.0
Florida Peninsula							70.5	+.6										71	2.19	+.2										3.5		
Key West	22	10	64	30.03	30.05	.00	73.8	+1.2	86	20	79	59	3	69	13	66	62	72	2.04	+.6	4	8,512	e.	30	w.	1	18	12	1	2.9	.0	.0
Miami	25	124	168	30.05	30.08	.00	70.9	+.7	82	20	77	44	4	65	26	63	59	70	1.69	-.5	7	8,657	se.	37	sw.	7	17	9	5	4.2	.0	.0
Tampa	35	88	197	30.04	30.08	+.01	66.8	.0	86	17	76	44	4	57	27	58	53	71	2.85	+.4	4	8,760	n.	34	s.	7	17	11	3	3.5	.0	.0
Titusville	44	5		30.01	30.06		65.6		88	15	76	43	22	55	29				2.72		3		se.				18	10	3	3.4	.0	.0
East Gulf States							58.1	+.6										68	5.85	+.7										4.6		
Atlanta	1,173	190	198	28.81	30.06	.00	52.4	+.4	79	18	62	27	3	42	33	44	37	62	4.42	-.9	9	8,774	nw.	32	w.	23	16	5	10	4.3	T	T
Macon	370	76	84	29.68	30.08	+.02	56.8	+.1	81	14	68	31	4	45	36	47	40	60	3.17	-1.8	10	6,385	nw.	30	s.	31	14	6	11	4.5	.0	.0
Thomasville	273	49	103	29.78	30.08	+.02	60.6	+.4	84	15	72	35	4	50	33	52	46	68	5.55	+1.5	7	6,846	s.	29	sw.	7	17	8	6	4.2	.0	.0
Apalachicola	36	11	51	30.04	30.08		61.3		79	15	68	41	4	54	21	55	52	76	3.76	-.5	5	7,410	s.	38	s.	20	18	10	3	3.4	.0	.0
Pensacola	56	149	185	30.02	30.08	+.02	60.4	+.1	74	23	67	35	21	54	26	56	52	80	7.24	+2.5	5	10,034	se	46	s.	6	16	11	4	3.6	.0	.0
Anniston	741	9	57				54.6	+2.1	82	18	67	25	4	42	38				5.98	+.3	9		sw.				11	10	10		.0	.0
Birmingham	700	11	48	29.29	30.07	+.01	54.9	-.5	81	14	66	28	4	44	34	46	40	64	6.18	+.5	13	7,002	n.	40	se.	6	12	10	9	4.9	T	.0
Mobile	57	125	161	30.01	30.06	.00	60.3	+.6	80	23	68	35	21	52	28	54	49	73	6.39	+.4	7	7,908	s.	34	se.	6	10	12	9	5.2	.0	.0
Montgomery	223	100	112	29.82	30.08	+.02	58.3	+.5	84	14	68	34	4	48	31	49	42	61	10.65	+4.7	8	6,587	sw.	23	n.	1	11	10	10	4.7	.0	.0
Corinth	469	6					53.6		84	29	65	28	10	42	40				7.24		11		se.				4	18	9		T	.0
Meridian	375	87	95	29.66	30.06	+.01	57.8	+.7	84	14	69	31	21	47	33	49	43	65	5.73	+.5	9	5,582	s.	28	w.	31	12	10	9	4.5	.0	.0
Vicksburg	247	65	73	29.78	30.04	.00	59.3	+.8	84	18	69	36	21	50	28	51	44	63	5.03	-.5	9	6,891	s.	32	w.	31	8	12	11	5.8	.0	.0
New Orleans	53	76	84	30.00	30.05	+.01	63.9	+1.1	83	18	72	41	21	56	27	57	52	72	6.15	+1.4	7	5,993	se.	20	sw.	31	12	11	8	5.0	.0	.0
West Gulf States							60.7	+1.5										72	3.18	+.4										6.0		
Shreveport	249	92	227	29.75	30.02	.00	59.0	+.7	87	14	69	34	21	49	36	51	45	67	6.25	+2.1	10	9,773	se.	46	se.	5	8	13	10	5.7	.0	.0
Bentonville	1,303	11	44	28.58	29.96	-.05	48.6	+1.3	82	13	59	19	21	38	34				2.19		9	5,797	se.	21	ne.	14	9	7	15		1.2	.0
Fort Smith	457	79	94	29.50	29.99	-.02	52.6	.0	85	13	63	26	21	43	32	46	39	67	2.56	-.4	9	7,834	e.	31	nw.	31	8	9	14	6.0	T	.0
Little Rock	357	136	153	29.65	30.03	.00	52.7	-.3	84	14	62	27	21	43	37	45	38	64	5.30	+.7	12	7,037	e.	29	sw.	13	8	8	15	6.5	T	.0
Austin	605	136	148	29.34	29.97		64.2	+3.5	87	18	74	37	1	54	35	56	49	66	1.64	-.7	11	7,035	se.	38	nw.	5	8	7	16	6.2	.0	.0
Brownsville	57	83	100	29.88	29.94		70.0	+1.8	85	18	77	44	1	63	35	64	62	83	.40	-.9	7	9,685	se.	35	se.	13	7	14	10	5.8	.0	.0
Corpus Christi	20	11	78	29.96	29.98	.00	67.5	+2.5	84	31	74	45	1	62	24	62	60	84	.47	-1.1	6	9,966	s.	43	s.	30	4	15	12	6.5	.0	.0
Dallas	512	220	227	29.44	29.99		58.2		88	13	68	30	20	49	34				2.86	.0	8	10,417	se.	36	n.	30	12	7	12	5.1	.0	.0
Fort Worth	670	106	114	29.26	29.97	-.01	59.2	+1.5	92	13	70	31	20	49	38	50	42	61	2.18	-.1	4	7,837	nw.	28	e.	30	5	7	19	6.9	.0	.0
Galveston	54	106	114	29.95	30.01	.00	63.2	+.8	80	31	68	41	20	59	19	60	57	84	5.52	+2.8	11	9,197	se.	34	nw.	6	8	11	12	5.9	.0	.0
Houston	138	292	314	29.87	30.02		63.6	+.3	85	14	71	38	20	56	26				3.07	-.4	12	10,646	se.	38	se.	5	8	8	15	6.3	.0	.0
Palestine	510	64	72	29.47	30.01	+.01	60.0	+.9	85	13	70	30	20	50	33	52	46	66	6.33	+2.8	9	7,518	s.	29	w.	31	8	11	12	6.0	.0	.0
Port Arthur	34	58	66	29.98	30.02		63.4		82	31	70	40	20	57	23	56	54	85	6.37	+3.1	9	7,121	se.	30	nw.	19	9	15	7	5.1	.0	.0
San Antonio	693	242	301	29.24	29.95	-.03	65.8	+3.0	90	18	76	40	1	56	32	57	50	65	.54	-1.3	10	7,347	e.	31	e.	23	9	7	15	6.0	.0	.0
Taylor	571	38	51	29.40	30.00	+.01	63.3	+3.6	85	14	74	37	20	53	35				.97	-1.1	6	7,975	s.	29	sw.	22	8	12	11	5.6	.0	.0

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1933*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
Ohio Valley and Tennessee							**43.7**	**−0.05**										**71**	**5.89**	**+1.7**										**6.8**		
Chattanooga	762	190	215	29.26	30.08	+.02	51.0	−.2	78	18	61	27	10	41	35	44	36	63	6.19	+.4	14	7,265	sw.	38	sw.	31	12	9	10	5.2	T	0.0
Knoxville	995	79	97	28.98	30.06	.00	49.0	+.3	75	18	59	26	10	39	31	42	35	64	3.30	−1.8	13	6,421	sw.	31	sw.	19	11	7	13	5.5	T	.0
Memphis	399	78	86	29.61	30.04	.00	52.4	+.1	80	14	61	30	10	44	33	46	39	66	6.87	+1.6	12	6,680	e.	35	w.	31	11	6	14	5.7	T	.0
Nashville	546	168	191	29.48	30.07	+.02	49.4	+.2	80	14	59	24	10	40	33	43	36	65	6.14	+1.0	11	8,391	nw.	50	w.	14	9	6	16	6.2	T	.0
Lexington	989	193	230	28.97	30.07	+.02	42.6	−1.1	71	14	51	15	10	34	28				4.75	+.4	12	10,690	e.	47	s.	31	12	7	12	5.1	T	.0
Louisville	525	188	234	29.46	30.05	.00	44.2	−1.2	75	14	53	16	10	36	35	40	34	70	6.11	+1.7	12	8,917	nw.	40	nw.	8	7	7	17	6.7	T	.0
Evansville	431	76	116	29.57	30.05	+.02	45.1	−.8	75	13	53	17	10	37	29	40	34	69	5.01	+.8	14	8,021	n.	37	sw.	13	8	8	15	6.4	T	.0
Indianapolis	822	194	230	29.12	30.02	−.02	39.6	−.4	70	13	47	10	10	32	27	35	30	70	6.20	+2.3	15	9,168	nw.	38	w.	8	3	9	19	7.5	2.7	.0
Terre Haute	575	96	129	29.40	30.02		41.8		76	13	50	11	10	34	25	37	32	72	5.81	+2.0	14	7,999	nw.	35	w.	8	6	8	17	7.0	2.3	.0
Cincinnati	627	11	51	29.34	30.04	−.01	41.7	+.8	75	14	50	14	10	33	35	37	32	74	8.00	+4.1	13	6,924	nw.	32	sw.	8	3	9	19	7.3	.1	.0
Columbus	822	216	230	29.13	30.02	−.02	39.4	+.3	70	14	47	12	10	32	27	35	30	73	5.44	+1.9	13	9,818	nw.	54	w.	8	2	11	18	7.6	3.3	.0
Dayton	899	137	173	29.05	30.03		40.0	−.5	70	14	47	12	10	33	30	36	31	75	5.98	+2.3	15	7,646	nw.	35	w.	8	3	8	20	7.8	3.2	.0
Elkins	1,947	59	67	27.94	30.06	+.01	37.6	−2.4	69	14	47	4	11	28	50	33	29	77	6.30	+2.5	22	6,266	nw.	34	w.	8	2	11	18	7.8	12.3	.0
Parkersburg	637	77	82	29.39	30.06	+.01	42.2	−.6	73	14	50	14	11	34	38	37	34	80	6.43	+2.9	15	6,009	nw.	34	nw.	8	5	5	21	7.7	.5	.0
Pittsburgh	842	353	410	29.09	30.02	−.02	38.0	−1.6	71	14	45	11	10	31	31	34	28	72	5.77	+2.7	18	8,606	nw.	41	w.	8	2	8	21	8.1	2.7	.0
Lower Lake Region							**33.1**	**+.2**										**76**	**3.31**	**+.6**										**7.8**		
Buffalo	767	243	280	29.11	29.97	−.05	30.8	−.3	57	31	36	9	10	26	24	28	26	83	2.85	+.3	23	12,311	sw.	54	w.	9	4	5	22	7.9	10.5	T
Canton	448	10	61	29.45	29.94		25.6	−2.1	51	31	33	−4	6	18	27				2.59	+.1	14	7,587	w.	35	w.	9	6	7	18	7.0	12.1	T
Ithaca	836	74	100	29.03	29.95		33.6	+1.8	64	14	40	10	10	27	26	30	26	77	3.26	+1.0	19	8,891	nw.	35	nw.	10	2	7	22	8.4	9.8	.0
Oswego	335	71	85	29.58	29.96	−.05	32.0	+.8	48	31	36	11	10	28	20	29	24	73	3.32	+.7	17	9,547	nw.	35	sw.	9	3	5	23	8.1	8.0	.0
Rochester	523	86	102	29.39	29.98	−.04	32.6	+.8	56	31	37	11	10	28	18	29	24	72	4.39	+1.6	20	7,932	w.	35	w.	9	6	4	21	7.5	8.0	.0
Syracuse	596	65	79	29.30	29.96	−.06	33.1	+1.7	51	31	38	10	11	28	21				4.22	+1.2	22	6,825	e.	27	nw.	10	2	10	19	8.0	13.2	.0
Erie	714	130	166	29.19	29.98	−.04	33.6	+.1	62	31	40	10	11	28	27	31	27	79	2.74	+.1	16	9,990	nw.	38	w.	9	4	4	23	8.0	8.6	.0
Cleveland	762	267	337	29.15	29.99	−.04	35.8	+1.2	68	31	42	10	10	30	27	32	27	74	3.51	+.8	16	11,606	w.	43	w.	9	2	8	21	8.2	5.0	.0
Sandusky	629	5	67	29.32	30.02	−.01	35.8	+.7	64	31	42	10	10	29	32				3.27	+.6	14	8,392	nw.	34	w.	9	2	6	23	8.1	5.2	.0
Toledo	628	79	87	29.32	30.02	−.01	35.1	−.2	61	31	41	8	10	29	31	31	26	71	3.33	+.8	12	8,276	nw.	32	nw.	8	7	5	19	7.0	3.5	.0
Fort Wayne	857	69	84	29.07	30.02		35.6	−3.3	60	13	42	10	10	30	30	32	28	76	4.00	+.8	11	7,956	nw.	35	nw.	8	0	12	19	8.2	4.8	.0
Detroit	730	218	258	29.20	30.01	−.02	34.0	+.6	57	31	40	8	10	28	26	31	27	80	2.25	−.2	15	8,517	nw.	32	w.	9	3	7	21	7.7	7.0	.0
Upper Lake Region							**28.8**	**+.5**										**80**	**2.23**	**+.1**										**7.6**		
Alpena	609	13	80	29.33	30.02	−.01	27.4	+1.9	49	16	33	4	10	22	39	25	22	81	1.53	−.5	13	9,935	nw.	37	nw.	9	6	8	17	7.0	5.2	.0
Escanaba	612	54	60	29.38	30.07	+.03	24.9	+.7	51	16	31	−4	10	18	37	23	19	80	1.46	−.4	11	8,642	n.	30	nw.	8	6	6	19	7.5	9.5	T
Grand Haven	632	54	89	29.32	30.02	−.01	31.4	−.3	57	31	37	8	10	26	27	30	27	83	2.53	+.1	13	9,025	nw.	50	w.	8	2	4	25	8.6	11.0	.0
Grand Rapids	707	70	244	29.22	30.01	−.02	33.1	−.3	59	31	39	6	10	27	28	30	26	77	2.13	−.4	13	9,422	n.	41	w.	8	2	7	22	8.5	8.2	.0
Houghton	668	64	99	29.31	30.06	+.02	23.1	+.3	46	29	30	−2	9	16	39				1.27	−.7	11	7,928	w.	43	w.	8	3	8	20	7.9	11.4	20.0
Lansing	878	66	88	29.04	30.01		31.8	−.4	61	31	38	6	10	26	28	30	28	89	2.25	−.1	12	7,998	nw.	32	w.	8	4	4	23	7.7	6.3	.0
Ludington	637	60	66	29.30	30.02		30.4	+.3	51	31	35	7	9	26	24	28	25	81	1.77	−.5	13	8,206	n.	34	nw.	8	4	5	22	7.5	9.6	.0
Marquette	734	77	111	29.24	30.06	+.02	24.7	−.1	50	16	30	0	10	19	40	23	20	84	1.95	−.3	16	7,626	nw.	36	sw.	16	2	6	23	8.3	18.6	3.0
Port Huron	638	79	120	29.28	29.99	−.04	31.1	+.7	54	31	36	8	10	26	21	29	25	80	2.63	+.5	17	9,457	nw.	36	w.	9	2	7	22	8.3	8.9	.0
Sault Sainte Marie	614	11	52	29.33	30.06	+.03	24.0	+2.4	40	31	31	−5	10	17	34	22	19	84	2.68	+.8	17	7,261	nw.	35	nw.	9	10	5	16	6.5	21.3	.8
Chicago	673	7	131	29.28	30.03	.00	35.4	+.1	69	31	41	6	10	30	33	32	27	74	4.05	+1.5	15	8,849	ne.	38	nw.	8	6	5	20	7.2	6.5	.0
Green Bay	617	109	141	29.35	30.04	.00	28.9	+.3	55	16	35	−1	10	22	34	26	21	75	2.26	+.2	7	9,919	n.	40	ne.	19	7	4	20	7.5	18.5	.0
Milwaukee	681	97	221	29.28	30.03	.00	32.7	+.6	62	12	38	2	10	27	33	30	25	75	3.93	+1.5	11	10,135	n.	37	nw.	8	5	9	17	7.2	12.9	T
Duluth	1,133	5	47	28.81	30.08	+.02	24.0	+.3	44	26	32	−13	9	17	39	21	18	83	.79	−.8	11	10,255	ne.	51	nw.	14	10	4	17	6.2	3.1	T
North Dakota							**29.2**	**+6.8**										**75**	**.44**	**−.4**										**5.7**		
Moorhead	940	50	58	29.04	30.10	+.02	28.0	+5.3	56	28	37	−5	9	20	32	25	21	78	.37	−.6	7	7,047	s.	35	nw.	8	10	5	16	6.3	3.1	.0
Bismarck	1,674	8	57	28.22	30.06	.00	31.0	+6.8	64	31	42	−2	9	21	38	26	20	70	.68	−.2	2	7,004	e.	37	nw.	8	9	13	9	5.5	7.1	.0
Devils Lake	1,478	11	44	28.46	30.09	+.04	25.8	+6.0	60	31	35	−8	9	16	32	23	19	82	.27	−.5	4	7,438	se.	43	nw.	7	8	9	14	6.0	3.6	.0
Ellendale	1,457	10	56	28.48	30.08		29.8		65	31	42	−5	10	18	44				.60	−.2	5	9,868	ne.	47	nw.	8	6	14	11	5.8	4.1	.0
Grand Forks	833	12	67				26.4		57	31	35	−7	9	18	32	23			.40		5		nw.	45	nw.	8	7	19	5		2.2	T
Williston	1,878	41	48	28.00	30.04	.00	31.9	+9.0	69	28	41	−3	9	23	37	27	22	71	.29	−.4	4	6,268	se.	40	w.	7	12	11	8	4.8	2.2	.0
Upper Mississippi Valley							**37.3**	**+1.2**										**74**	**3.61**	**+1.3**										**6.6**		
Minneapolis	918	102	208	29.04	30.05		30.6	+1.0	57	16	38	−2	9	24	32				2.15	+.7	8	9,241	n.	38	nw.	8	9	5	17	6.6	4.7	.0
St. Paul	837	114	149	29.12	30.06	+.01	31.2	+2.1	59	16	38	0	9	24	30				2.15	+.7	8	7,397	n.	33	nw.	8	8	9	14	6.2	5.0	.0
La Crosse	714	11	48	29.24	30.04	.00	32.3	+.8	63	12	40	2	10	24	38	29	25	76	3.05	+1.4	8	5,017	nw.	24	nw.	8	7	5	19	6.9	18.7	.0
Madison	974	70	78	28.95	30.04	.00	31.0	+.4	64	12	38	0	10	24	38	28	24	78	2.68	+.6	10	7,788	nw.	30	ne.	19	5	8	18	7.2	9.1	T
Wausau	1,247	4	62	28.67	30.05		27.5		55	16	34	−6	10	21	34				1.10	−.6	6	6,228	nw.	27	nw.	8	5	10	13	6.5	8.4	.0
Charles City	1,015	10	51	28.93	30.05	.00	32.0	+1.3	65	12	41	0	10	23	37	28	24	78	4.32	+2.6	9	6,227	nw.	25	nw.	8	11	8	12	5.6	10.1	.0
Davenport	606	118	143	29.35	30.03	.00	37.4	+1.3	67	30	45	6	10	30	33	33	29	74	2.81	+.9	12	8,383	nw.	40	nw.	8	6	7	18	7.1	2.0	.0
Des Moines	861	5	99	29.10	30.03	−.01	37.4	+1.5	73	13	47	7	10	28	33	33	28	78	2.19	+.4	9	8,089	n.	35	nw.	14	7	7	17	6.7	1.8	.0
Dubuque	700	81	96	29.27	30.04	−.01	35.0	+1.0	67	12	42	4	10	28	41	31	26	73	4.76	+2.7	8	5,564	nw.	26	nw.	8	8	7	16	6.8	7.8	T
Keokuk	614	64	78	29.35	30.04	+.01	40.2	+1.3	75	13	49	9	10	32	29	35	29	68	2.31	−.1	11	6,632	n.	28	nw.	8	6	8	17	6.8	3.1	.0
Cairo	358	87	93	29.64	30.03	−.01	47.6	+.4	78	13	56	22	10	40	32	43	38	74	6.39	+2.6	14	7,877	n.	33	n.	14	6	8	17	7.0	T	.0
Peoria	609	11	45	29.36	30.04	+.01	39.4	+2.4	77	13	48	8	10	31	33	34	30	75	4.70	+2.0	10	6,427	nw.	28	nw.	8	8	5	18	6.5	4.1	.0
Springfield, Ill.	636	5	191	29.33	30.02	−.01	41.9	+1.7	82	13	51	11	10	33	30	37	32	75	6.50	+3.3	15	9,305	s.	34	nw.	8	8	8	15	6.4	4.6	.0
Hannibal	534	74	109	29.43	30.02	.00	41.8	+.8	77	13	50	11	10	33	32				4.05	+1.4	13	7,003	nw.	29	w.	13	4	11	16	6.7	4.4	.0
St. Louis	568	265	303	29.40	30.02	−.01	44.8	+1.0	85	13	54	14	10	36	33	39	33	69	4.91	+1.5	15	9,323	s.	36	w.	13	10	9	12	5.6	.1	.0
Missouri Valley							**40.1**	**+2.5**										**71**	**2.78**	**+1.0**										**5.7**		
Columbia, Mo.	784	6	84	29.16	30.01	−.02	44.0	+1.4	79	13	53	15	10	35	32				3.27	+.3	11	7,244	se.	27	n.	14	8	9	14	5.9	1.1	.0
Kansas City	963	10	86	28.95	30.01	−.01	44.2	+1.5	78	30	53	13	10	36	30	38	32	67	4.25	+1.7	11	8,853	se.	36	sw.	30	8	11	12	5.5	2.6	.0
St. Joseph	967	11	49	28.94	30.00		42.6		80	30	52	12	10	33	37	37	30	68	2.81	+.8	10	7,997	se.	30	nw.	25	9	11	11	5.5	1.4	.0
Springfield, Mo.	1,324	98	104	28.57	29.99	−.03	46.2	+1.0	79	13	56	18	21	37	33	40	35	71	2.40	−1.0	10	9,014	se.	31	se.	24	11	7	13	5.7	.9	.0
Iola	984	11	50	28.92	29.98	−.03	48.0	+3.5	82	13	60	16	21	36	42				2.86	+.2	7		e.				7	11	14		T	.0
Topeka	987	92	107				44.2	+1.6	80	30	54	14	10	34	41				2.01	−.1	8	8,824	se.	32	nw.	14	11	10	10	5.2	1.7	.0
Lincoln	1,189	11	81	28.71	30.01	−.01	39.4	+1.9	75	29	49	5	10	30	37	35	30	72	3.40	+2.1	8	8,572	n.	30	nw.	25	11	8	12	5.7	8.8	.0
Omaha	1,105	115	122	28.82	30.01	−.01	39.0	+2.0	72	29	48	10	10	30	30	33	28	69	3.25	+1.9	9	7,534	n.	30	nw.	8	11	7	13	5.9	17.6	.0
Valentine	2,598	47	54	27.25	30.03	.00	35.0	+2.7	73	28	46	4	9	24	41	30	26	74	2.87	+1.8	7	7,229	n.	30	nw.	24	8	8	15	6.3	22.3	.0
Sioux City	1,135	94	164	28.79	30.04	−.01	35.4	+2.7	71	29	44	7	10	27	25	31	27	74	2.67	+1.5	8	9,155	n.	37	nw.	8	9	6	16	6.3	14.0	.0
Huron	1,306	59	74	28.62	30.05	−.01	33.8	+4.9	67	31	44	−4	10	24	35	29	24	74	1.49	+.6	6	7,813	se.	25	se.	29	10	13	8	5.3	9.0	.0
Pierre	1,572	70	75	28.33	30.04	−.01	36.2	+4.7	74	28	46	3	9	26	37	30	24	69	2.40	+1.4	7	7,290	nw.	34	ne.	17	11	12	8	5.0	10.0	.0
Yankton	1,233	49	57	28.70	30.05	.00	35.5	+2.3	73	29	44	7	10	27	30				2.66	+1.4	8	6,548	e.	27	nw.	13	10	8	13	5.9	11.8	.0

TABLE 1.—*Climatological data for Weather Bureau stations, March, 1933*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with .01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							35.6	+4.2										65	0.75	−0.2										6.1		
Billings	3,140	5	----	----	----	----	40.8	----	76	28	55	9	9	26	46	----	----	----	1.04	----	10	----	nw.	----	----	----	6	9	16	----	2.5	0.0
Havre	2,505	11	67	27.31	30.00	0.00	35.0	+7.9	68	28	48	−16	9	22	43	29	22	64	.39	−.1	7	6,419	sw.	35	w.	7	9	16	6	5.1	5.4	.0
Helena	4,124	89	113	25.74	30.00	−.01	36.4	+4.0	60	28	46	6	9	27	38	30	21	56	.22	−.6	4	6,088	sw.	28	sw.	3	3	11	17	7.1	4.9	.0
Kalispell	2,973	48	56	26.91	30.02	+.03	35.5	+2.6	50	29	43	13	9	28	23	32	29	79	.21	−.7	8	4,571	nw.	25	sw.	7	3	11	17	7.2	1.6	.0
Miles City	2,371	48	55	27.43	30.04	+.02	37.1	+8.5	70	28	47	6	9	27	36	32	26	69	.66	−.2	10	4,721	s.	29	nw.	7	8	14	9	5.5	3.3	.0
Rapid City	3,259	50	58	26.54	30.04	+.03	36.2	+3.6	75	28	47	7	9	25	44	30	24	67	1.36	+.4	9	6,817	n.	32	nw.	7	9	13	9	5.6	11.7	.0
Cheyenne	6,088	84	101	23.91	29.97	+.01	35.4	+2.3	65	28	46	11	23	24	33	28	18	52	.88	−.1	10	11,011	w.	47	w.	7	4	16	11	6.5	9.1	.0
Lander	5,372	60	68	24.57	29.99	.00	36.2	+3.8	63	28	48	14	15	24	37	30	21	61	.84	−.4	7	4,524	sw.	34	w.	10	12	14	5	4.3	6.6	.0
Sheridan	3,790	10	47	26.04	30.02	----	34.2	----	67	12	46	3	23	22	39	29	24	70	1.80	+.6	8	4,535	nw.	27	nw.	3	7	11	13	6.1	16.9	.1
Yellowstone Park	6,241	11	48	23.82	30.08	+.06	28.4	+1.9	51	28	38	0	5	18	34	23	17	65	.54	−1.1	9	6,716	sw.	27	sw.	12	4	9	18	7.3	9.0	T
North Platte	2,821	11	51	27.00	29.97	−.03	40.2	+3.6	79	29	52	16	20	28	43	33	25	63	.62	−.2	7	7,006	n.	30	n.	18	8	8	15	6.4	5.1	.0
Middle Slope							46.0	+2.7										56	1.40	+.2										5.2		
Denver	5,292	106	113	24.63	29.92	−.03	43.0	+3.7	70	31	55	20	6	31	38	32	17	41	1.32	+.3	9	6,894	s.	38	n.	18	5	18	8	5.7	9.0	.0
Pueblo	4,685	80	86	25.21	29.92	.00	44.0	+2.4	76	28	59	12	6	29	54	33	18	42	.43	−.2	2	5,969	n.	32	w.	12	10	18	3	4.8	3.4	.0
Concordia	1,392	50	58	28.52	30.02	+.01	43.0	+2.0	76	29	53	15	21	33	37	37	31	72	1.97	+.7	7	7,589	n.	27	s.	29	9	9	13	5.9	4.7	.0
Dodge City	2,509	10	86	27.35	29.97	.00	46.3	+3.5	77	26	60	16	20	32	45	36	25	52	.09	−.8	5	11,385	s.	36	se.	22	15	13	3	3.7	.6	.0
Wichita	1,358	85	93	28.52	29.96	−.03	47.6	+2.5	82	13	58	18	10	37	40	40	31	59	1.72	.0	4	9,661	s.	32	sw.	29	7	13	11	5.7	.9	.0
Oklahoma City	1,214	10	47	28.67	29.96	−.02	52.0	+2.0	83	13	63	23	20	41	36	44	36	62	2.88	+.9	6	8,491	s.	29	s.	30	9	10	12	5.7	2.4	.0
Southern Slope							57.2	+2.6										49	.34	−.5										5.1		
Abilene	1,738	10	52	28.15	29.96	.00	59.5	+3.0	89	13	72	31	20	47	37	48	38	54	.70	−.6	3	8,604	s.	30	s.	4	6	13	12	6.2	T	.0
Amarillo	3,676	10	49	26.21	29.94	−.01	50.8	+3.9	82	12	65	26	20	37	43	38	23	41	.56	−.2	3	8,521	se.	30	sw.	18	14	14	3	4.2	T	.0
Big Spring	2,537	5	62	27.34	29.96	----	58.1	----	85	29	72	28	20	44	40	46	35	53	.11	----	3	----	s.	----	----	----	8	17	6	5.1	T	.0
Del Rio	944	64	71	28.92	29.91	−.04	65.4	+1.9	92	13	77	37	6	54	44	55	45	57	.10	−.6	5	7,340	se.	30	nw.	5	9	8	14	5.9	.0	.0
Roswell	3,566	75	85	26.32	29.92	+.02	53.0	+1.7	82	12	69	26	6	37	47	40	23	40	T	−.7	0	6,828	s.	32	nw.	30	15	12	4	4.1	.0	.0
Southern Plateau							52.6	+1.8										36	.06	−.5										3.5		
El Paso	3,778	152	175	26.14	29.90	+.02	58.9	+3.1	83	28	72	31	6	45	35	42	19	25	T	−.4	0	8,478	w.	39	w.	21	21	7	3	3.1	.0	.0
Albuquerque	4,972	51	66	25.00	29.90	----	47.2	----	76	28	64	22	14	30	45	34	14	34	.09	----	2	7,984	nw.	41	w.	17	15	11	5	4.2	0.9	.0
Santa Fe	7,013	38	53	23.18	29.91	+.02	41.8	+2.1	66	28	54	14	5	30	33	30	14	35	.29	−.5	4	5,630	n.	25	sw.	17	14	9	8	4.5	4.5	.0
Flagstaff	6,907	10	59	23.30	29.92	+.01	37.6	+1.7	64	27	53	12	6	22	43	30	----	56	.06	----	2	6,845	sw.	29	sw.	23	14	14	3		T	.0
Phoenix	1,108	10	107	28.78	29.93	+.02	61.9	+1.2	83	27	77	38	6	47	37	46	27	31	.00	−.7	0	4,706	e.	24	nw.	4	16	10	5	3.7	.0	.0
Yuma	141	9	54	29.81	29.96	+.02	65.2	+1.1	88	27	81	45	26	50	40	49	29	32	.00	−.3	0	4,939	w.	30	n.	19	23	6	2	2.1	.0	.0
Independence	3,957	6	27	25.97	30.01	+.07	50.4	+1.9	78	31	66	22	24	35	40	37	----	----	T	−.5	0	----	nw.	----	----	----	18	8	5	----	.0	.0
Middle Plateau							41.2	+.3										50	.63	−.5										5.5		
Reno	4,532	74	81	25.45	30.02	+.04	43.0	+2.0	69	31	55	21	22	31	35	35	24	47	.34	−.5	3	6,158	w.	31	w.	2	9	12	10	5.2	.5	.0
Tonopah	6,090	12	20	----	----	----	40.4	----	62	31	50	22	22	31	30	32	19	42	.02	----	1	----	nw.	----	----	----	----	----	----	----	----	----
Winnemucca	4,344	18	56	25.62	30.05	+.04	39.8	−.2	68	27	53	17	4	27	39	33	24	58	.76	−.2	5	5,843	sw.	29	sw.	12	6	13	12	6.3	5.8	.0
Modena	5,473	10	46	24.58	29.97	+.01	39.0	+.8	68	31	53	18	5	26	43	31	19	51	.28	−.8	2	7,587	sw.	38	w.	28	12	11	8	5.0	1.4	.0
Salt Lake City	4,360	163	203	25.63	30.05	+.07	40.8	−.9	69	28	50	18	5	32	29	34	25	55	1.44	−.5	7	5,198	nw.	26	nw.	29	9	7	15	5.9	4.1	.0
Grand Junction	4,602	60	68	25.34	29.94	.00	43.4	−.2	74	28	56	22	5	31	36	34	21	47	.31	−.4	5	5,151	n.	32	nw.	13	10	13	8	5.0	T	.0
Northern Plateau							40.9	−1.0										64	.87	−.3										7.1		
Baker	3,471	48	53	26.46	30.10	+.07	34.9	−2.7	53	28	43	13	4	26	26	32	26	70	1.00	−.1	14	5,345	se.	21	se.	15	2	17	12	7.0	3.7	.0
Boise	2,739	79	87	27.20	30.10	+.07	41.2	−1.5	65	27	51	22	4	32	28	35	27	60	.59	−.8	8	5,154	se.	27	nw.	12	0	16	15	7.6	.8	.0
Lewiston	757	40	48	29.24	30.07	+.04	46.0	+.6	64	27	55	26	9	37	30	----	----	----	.60	−.6	11	3,656	e.	23	nw.	20	2	12	17	7.5	T	.0
Pocatello	4,477	60	68	25.48	30.08	+.07	35.2	−2.2	61	28	44	10	5	26	31	30	24	65	.42	−.9	8	7,482	se.	32	sw.	21	6	11	14	6.4	3.4	.0
Spokane	1,929	101	110	27.96	30.05	+.04	40.2	+.5	57	15	48	23	9	33	25	35	30	69	1.19	.0	13	5,289	s.	22	sw.	30	3	12	16	7.4	2.0	.0
Walla Walla	991	57	65	28.96	30.04	+.02	45.8	−.3	64	15	54	26	9	38	27	40	31	58	1.32	−.3	13	4,980	s.	32	w.	2	2	14	15	7.2	T	.0
Yakima	1,076	58	67	28.87	30.04		42.8	−1.3	61	18	52	25	9	33	20	37	29	50	.99	+.6	8	4,089	nw.	26	nw.	20	5	12	14	6.6	.2	.0
North Pacific Coast Region							45.2	.0										76	5.56	+1.7										8.0		
North Head	211	11	56	29.79	30.02	+.01	44.1	−1.1	57	14	48	36	9	40	15	42	40	87	10.48	+4.9	26	12,244	s.	65	s.	11	3	4	24	8.0	.0	.0
Port Angeles	29	8	53	----	30.02	----	42.2	----	54	15	48	30	9	36	18	----	----	----	1.82	−.4	15	4,853	s.	45	s.	20	2	11	18	----	.0	.0
Seattle	125	215	250	29.88	30.01	+.02	45.0	+.1	62	14	51	34	21	39	22	41	36	74	5.20	+2.2	22	6,458	se.	30	sw.	3	2	12	17	7.4	T	.0
Tacoma	194	172	201	29.81	30.02	+.02	44.8	+.6	60	15	52	32	4	38	21	----	----	----	5.92	+2.4	25	6,225	s.	27	s.	3	3	7	21	7.7	T	.0
Tatoosh Island	86	9	53	29.88	29.97	+.01	43.4	+.5	53	14	47	34	2	40	12	41	38	83	12.87	+5.0	23	11,230	e.	45	e.	11	2	5	24	8.1	.1	.0
Medford	1,329	29	58	28.62	30.04	----	46.0	----	70	19	57	25	23	35	34	40	34	67	.91	−.8	11	5,045	nw.	34	se.	11	3	5	23	8.2	.0	.0
Portland, Oreg.	153	68	106	29.89	30.05	+.03	47.0	+.1	63	19	54	33	23	40	22	43	38	73	5.10	+1.2	24	4,887	se.	21	sw.	30	0	8	23	8.6	T	.0
Roseburg	510	75	99	29.51	30.07	+.03	47.0	−.1	72	19	56	28	23	38	29	42	36	69	2.15	−1.1	16	3,878	s.	24	sw.	11	1	5	25	8.1	.0	.0
Middle Pacific Coast Region							53.6	+.8										73	3.01	−.3										6.1		
Eureka	62	73	89	30.04	30.11	+.05	49.0	+.7	63	10	55	36	4	43	19	47	45	87	7.20	+2.0	25	6,755	se.	30	sw.	2	3	9	19	7.5	.0	.0
Red Bluff	330	5	58	29.71	30.07	+.03	54.7	+1.1	79	19	64	36	17	45	31	48	42	66	2.02	−1.2	11	6,588	se.	31	se.	2	6	6	19	7.7	.0	.0
Sacramento	69	106	117	30.02	30.08	+.05	54.4	+.1	75	19	64	38	22	45	29	48	42	66	1.44	−1.1	10	6,324	s.	29	nw.	21	16	12	3	3.7	.0	.0
San Francisco	155	208	243	29.93	30.10	+.04	55.4	+1.2	73	19	62	44	23	49	23	49	45	74	2.93	−.2	11	5,396	w.	25	nw.	22	8	11	12	5.7	.0	.0
San Jose	141	12	110	29.97	30.12	----	54.4	+.8	75	19	64	36	22	44	32	----	----	----	1.47	−1.1	10	4,893	nw.	21	se.	16	8	12	11	5.8	.0	.0
South Pacific Coast Region							57.6	+1.2										64	.57	−1.5										4.6		
Fresno	327	89	98	29.74	30.10	+.09	56.2	+1.2	79	9	68	37	4	45	30	48	39	59	1.38	−.2	4	4,973	nw.	23	nw.	21	12	11	8	4.9	.0	.0
Los Angeles	338	159	191	29.69	30.06	+.04	59.7	+2.2	82	4	70	43	24	50	31	50	41	60	.19	−2.6	2	4,342	sw.	20	sw.	23	18	12	1	3.3	.0	.0
San Diego	87	62	70	29.95	30.04	+.02	57.0	+.3	80	20	65	45	26	49	29	51	47	74	.13	−1.6	3	4,765	nw.	19	nw.	24	7	16	8	5.6	.0	.0
West Indies																																
San Juan, P.R.	82	9	54	29.93	30.02	----	75.9	+.5	88	4	81	69	1	71	15	----	----	----	5.24	+2.1	18	10,268	e.	31	ne.	31	5	20	6	5.5	.0	.0
Panama Canal																																
Balboa Heights	118	6	97	----	[1]29.84	.00	80.6	−.6	91	8	89	68	21	73	20	----	----	[1]74	.46	−.3	2	7,634	nw.	27	n.	29	2	28	1	5.0	.0	.0
Cristobal	36	6	97	----	[1]29.88	.00	81.4	−.1	88	21	85	73	21	77	15	74	72	[1]76	1.11	−.4	13	10,864	n.	27	n.	28	4	20	7	5.7	.0	.0
Alaska																																
Fairbanks	455	11	44	[2]29.38	[2]29.94	----	8.3	----	45	15	23	−35	1	−6	50	8	1	64	.07	----	4	3,186	n.	22	se.	15	11	7	13	5.5	1.2	9.5
Juneau	80	11	50	[2]29.75	[2]29.84	----	32.6	----	49	16	38	9	1	28	21	29	22	64	3.91	----	14	6,619	s.	28	se.	16	9	6	16	6.4	3.3	.0
Hawaiian Islands																																
Honolulu	38	86	100	[2]30.03	[2]30.07	----	71.3	−.1	78	18	76	65	7	67	12	65	61	71	3.88	+.7	16	7,965	e.	35	sw.	3	6	12	13	6.5	.0	.0

[1] Observations taken bihourly.

[2] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, March 1933*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max.+mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	In.	In.	In.	°F.	°F.	°F.	°F.	°F.	°F.	In.	In.	In.
Cape Race, N.F.	99							23.8		13	2.71		14.5
Sydney, C.B.I.	48	29.69	29.74	−0.14	27.5	+1.3	33.7	21.2	43	8	5.86	+0.93	42.6
Halifax, N.S.	88	29.66	29.77	−.17	29.3	+.3	34.8	23.8	42	7	5.30	−.16	18.3
Yarmouth, N.S.	65	29.69	29.76	−.19	31.2	+.4	36.6	25.8	46	13	5.98	+.98	15.4
Charlottetown, P.E.I.	38	29.70	29.74	−.16	25.7	+.3	31.1	20.3	42	2	4.22	+1.01	31.7
Chatham, N.B.	28	29.71	29.74	−.16	21.3	−1.7	29.3	13.3	40	−10	2.64	−.83	24.4
Father Point, Que.	20	29.86	29.89	−.01	20.8	+.5	27.4	14.1	40	0	2.80	+.07	28.0
Quebec, Que.	296	29.60	29.94	−.02	22.5	+1.3	28.5	16.5	44	−3	3.99	+.73	39.6
Doucet, Que.	1,236				12.8		27.6	−1.9	45	−36	2.76		25.2
Montreal, Que.	187	29.71	29.93	−.07	26.0	+2.2	32.3	19.8	44	−2	3.41	−.38	30.2
Ottawa, Ont.	236	29.68	29.96	−.05	27.2	+5.7	34.9	19.5	48	−3	3.42	+.70	30.8
Kingston, Ont.	285	29.64	29.96	−.05	29.0	+3.4	34.9	23.2	45	3	3.42	+.78	6.4
Toronto, Ont.	379	29.55	29.98	−.04	31.6	+4.3	36.6	26.6	50	8	1.79	−.85	5.7
Cochrane, Ont.	930				15.4		25.7	5.0	42	−16	2.24		20.3
White River, Ont.	1,244	28.69	30.06	+.03	13.9	+1.7	28.4	−.5	47	−28	1.39	+.01	13.9
London, Ont.	808				29.6		34.8	24.5	50	1	3.53		9.7
Southampton, Ont.	656	29.24	29.97	−.06	27.2	+2.5	33.5	20.8	54	8	2.85	+.20	13.9
Parry Sound, Ont.	688	29.26	29.97	−.05	25.4	+4.3	32.7	18.1	45	−9	2.91	+.68	20.1
Port Arthur, Ont.	644	29.35	30.08	+.03	21.7	+4.9	30.1	13.4	42	−12	1.15	+.18	9.1
Winnipeg, Man.	760	29.25	30.12	+.03	17.1	+4.8	27.4	6.8	48	−19	.47	−.56	2.7
Minnedosa, Man.	1,690	28.22	30.12	+.06	16.7	+4.2	26.3	7.1	51	−25	.14	−.51	1.4
Le Pas, Man.	860				11.6		24.2	−1.0	52	−28	1.27		10.0
Qu'Appelle, Sask.	2,115	27.60	30.01	−.03	22.4	+7.5	31.3	13.6	57	−22	.53	−.24	5.1
Moose Jaw, Sask.	1,759												
Swift Current, Sask.	2,392	27.35	29.94	−.08	29.9	+7.9	40.7	19.2	68	−15	.32	−.49	3.2
Medicine Hat, Alb.	2,365	27.38	29.90	−.10	31.7	+4.2	42.4	21.1	62	−10	.75	−.01	5.9
Calgary, Alb.	3,540	26.17	29.95	.00	26.9	+.7	36.9	16.9	56	−17	.20	−.52	2.0
Banff, Alb.	4,521												
Prince Albert, Sask.	1,450	28.47	30.12	+.02	15.7	+3.7	26.0	5.4	44	−33	.73	−.04	7.1
Battleford, Sask.	1,592	28.24	30.05	−.01	16.9	+3.8	27.3	6.5	50	−29	1.31	+.85	11.7
Edmonton, Alb.	2,150												
Kamloops, B.C.	1,262												
Victoria, B.C.	230	29.73	29.99	+.02	44.0	+2.1	48.7	39.3	55	34	1.90	−1.22	T
Barkerville, B.C.	4,180												
Estevan Point, B.C.	20												
Prince Rupert, B.C.	170												
Hamilton, Ber.	151	29.90	30.07	−.01	62.8	+.6	67.7	58.0	75	51	2.60	−2.53	.0

LATE REPORTS FOR FEBRUARY 1933

Yarmouth, N.S.	65	29.69	29.76	−0.23	31.8	+6.0	37.9	25.6	50	10	4.85	+0.68	18.2
Kamloops, B.C.	1,262	28.72	29.98	+.02	23.7	−4.6	29.9	17.6	55	−12	.63	−.16	6.2
Estevan Point, B.C.	20				37.8		42.8	32.9	47	20	11.77		2.0
Prince Rupert, B.C.	170				33.9		38.2	29.7	50	19	6.96		6.3

SEVERE LOCAL STORMS, MARCH 1933

[Compiled by Mary O. Souder]

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Northeastern Nebraska	4–6					Heavy snow	6 to 30 inches of snow, breaking 24-hour record for March at several stations.	Official, U.S. Weather Bureau.
Shelby County, Tenn.	6	5:30 a.m.		2		Wind	7 persons injured when walls of hospital collapsed.	Do.
Chicot County, Ark.	6				$75,000	do	Dredge boat on Mississippi River capsized and 1 man drowned; property damaged.	Do.
Canton, N.Y.	8			1		Glaze and wind	Telephone poles down	Do.
Milwaukee, Wis.	8				1,500	Strong winds	Property damaged and lake traffic impeded	Do.
Ludington, Mich.	9	A.m.				Gale	Ice along shore plugged intake pipe; parts of city without water.	Do.
Nampa, Idaho	12	5–5:30 p.m.	[1] 9		15,000	Wind	Damage to telephone and power lines; aerial tower of radio station demolished; path 9 miles long.	Do.
Northeastern Indiana	13	8:30 p.m.	[1] 1		100,000	Hail and tornado	Damage to property and to orchards; livestock killed; 1 person injured.	Do.
Allen and Hardin Counties, Ohio.	13	9–10 p.m.			150,000	Tornadic winds	Path strewn with wreckage of many farms, trees, telephone and telegraph poles.	Do.
Herman, Ark., and vicinity.	14	5 p.m.	433		17,000	Tornado	No lives lost; 6 persons injured; property damaged.	Do.
Nashville, Tenn.	14	7:30–8:15 p.m.	200–800	15	2,200,000	Tornado and hail	Much property damage; path 40 miles long. See p. 84, Monthly Weather Review, this issue.	Do.
Knox, Gibson, Pike, and Dubois Counties, Ind.	14	P.m.			34,500	Wind and hail	Damage to property and heavy loss in peach crop.	Do.
Harrodsburg, Ky., and vicinity.	14					do	No details	Do.
Dunklin and Pemiscot Counties, Mo.	14		880		200,000	Wind	Considerable damage to property	Do.
Montgomery and Bedford Counties, Va.	15	12:30–3:00 a.m.	1½–3		2,100	do	Property damage	Do.
Carmichael, Calif.	16	2:50 p.m.				Tornadic winds	Rose bushes uprooted; blackberry vines torn down; property damaged.	Do.
Lodi (near), Calif.	16	3 p.m.				Tornado	Garage shifted on foundation; instrument shelter overturned.	Do.

[1] Miles instead of yards.

SEVERE LOCAL STORMS, MARCH, 1933—Continued

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Delhi (near), Calif.	16	4:15 p.m.			2,000	Tornado	House and garage demolished; fruit trees uprooted.	Official U.S. Weather Bureau.
Spartanburg, S.C.	17	11:30 p.m.			6,000	Thundersquall	Dwelling demolished by wind; 2 persons injured; power lines demolished.	Do.
Benton to 11 miles south of Little Rock, Ark.	18	3:30 p.m.	200		15,000	Tornado	1 person injured; property damaged	Do.
Burnsville, Miss.	18	5:30 p.m.	100		5,000	Tornado	No details	Do.
Opelika, Ala., and vicinity.	18	6 p.m.	30	1	35,000	do	3 persons injured; many buildings destroyed; transmission lines torn down; path 1 mile long.	Do.
Horatio, Ark.	18				1,000	Tornadic winds	Property damaged	Do.
Iowa, southwest, center, northeast.	18–19		[1] 150		112,000	Glaze and heavy snow.	Weight of snow caused roofs to collapse; damage to telephone and telegraph lines; traffic delayed.	Do.
Ohio, extreme northwestern counties.	18–19				500	Glaze	Telephone wires damaged	Do.
Northern Illinois	18–20				8,000	Glaze and ice	Damage to power, telephone lines, trees and shrubbery.	Do.
Michigan, lower peninsula.	18–20					Rain, sleet, and ice.	Much damage to telegraph and telephone lines and to trees, motor traffic very hazardous.	Do.
Omaha, Nebr.	18–20				2,000	Rain, sleet, and snow.	Damage to greenhouses; traffic delayed	Do.
Milwaukee, Wis.	18–20					Sleet, wind, and snow.	½ inch of glaze formation on trees, poles and wires; roads and pavements slippery; property damaged.	Do.
Port Washington to Grant County, Wis.	18–20				100,000	Sleet, glaze, and wind.	Wires broken and 400 poles blown down; small damage to trees.	Do.
Grand Rapids, Mich.	19	10:20 a.m.–12:47 p.m.				Glaze	½ inch of ice on surfaces; motoring hazardous	Do.
Alice to Yoakum, Tex.	19	A.m.				Wind	Houses blown from foundations; crops damaged.	Do.
Jim Wells to Lavaca Counties, Tex.	19	A.m.				do	Windows blown in; several houses blown from their foundations.	Do.
Madison, Wis. (7 miles east of).	19	3 p.m.		1		Tornadic winds	House wrecked	Do.
Davenport, Iowa	19–20					Glaze and high wind.	Considerable trouble with overhead wires; much difficulty in walking and driving.	Do.
Northern lower Michigan.	19–20					Ice storm	No damage reported	Do.
Grand Rapids, Mich., and vicinity.	20	8:15 – 11 a.m.				do	Damage to wires	Do.
Ludington, Mich.	20	A.m.				Sleet and glaze	Little ice on overhead wires; highways icy at places.	Do.
Sea Bright, N.J.	20	A.m.			35,000	Wind	Residence washed out to sea	Do.
Jeffersonville, N.Y., and vicinity.	20				30,000	Glaze	Damage to telephone and power lines	Do.
Hazelhurst, Pa., and vicinity.	20					Ice storm	Ice 2 inches thick froze on trees, wires and all surfaces; many poles and wires down.	Do.
Springfield, Ill.						Heavy snow	Snow stuck to trees and bushes	Do.
Nantucket, Mass.	26–27					Snow and sleet	Snow frozen on wires did several thousand dollars damage.	Do.
Bridgeport, Okla.	26–27		[1] 4			Hail	Considerable property damage; loss not estimated.	Do.
Denver, Colo.	29	P.m.			2,500	Whirlwind	Property damaged	Do.
Hugo, Okla.	30	4:30 a.m.	[1] 4		60,000	Heavy hail	Property damaged; path 10 miles long	Do.
Mabank (near), Tex.	30	2:30 p.m.			2,000	Tornado	No other details	Do.
Apache, Okla.	30	3 p.m.				do	Storm confined to pasture lands with no damage or fatalities.	Do.
Fordice to Pennington, Tex.	30	3 p.m.			10,000	do	13 persons injured; property damaged	Do.
Lindale, Tex.	30	3 p.m.		2	75,000	do	Property damaged; 10 persons injured	Do.
Shelbyville, Tex.	30	3 p.m.		2	75,000	do	29 persons injured; property damaged	Do.
San Augustine, Tex.	30	3–6:30 p.m.		6	75,000	Tornadoes (2)	26 persons injured; property damaged	Do.
Henderson, Tex.	30	4–5 p.m.	440		4,000	Wind	Houses blown from foundations; corn had to be replanted.	Do.
Overbrook, Kans., (3 miles southeast of).	30	4:20 p.m.	75		1,000	Tornado	Property damage; path 1 mile long	Do.
Osage and Douglas Counties, Kans.	30	4:30 p.m.	250		2,000	do	Property damaged; path not continuous	Do.
Harmon and Hall Summit, La., and vicinity.	30	4:50–4:55 p.m.	[1] 1	5	62,000	do	Damage to property, trees and fences; many injured; path 20 miles long.	Do.
Mt. Holly, Ark. (5 miles south of).	30	5 p.m.	433	1	2,000	do	Damage to property; 4 persons injured	Do.
Oakland, Kans.	30	6 p.m.				Tornadic winds	No details	Do.
Huntington, Etoile, and San Augustine, Tex.	30	6:15–6:30 p.m.	400–1,760	4	125,000	Tornado	More than 30 injured; property damaged	Do.
Baird, Miss.	30	10 p.m.			5,000	High winds	Property damaged	Do.
Eudora, Ark.	30–31	P.m.	866		8,000	Tornado	Damage to property; path 5 miles long	Do.
Dubuque, Iowa	30–31					Electrical and heavy rain.	Trees and poles struck by lightning; basements flooded and sewers overflowed; damage to gardens.	Do.
Mississippi (13 counties).	30–31		33.800	54	235,000	Tornadoes	See Monthly Weather Review, p. 84, March 1933.	Do.
La Crosse, Wis., and vicinity.	30–31			3	64,000	Heavy rain and flood.	Property damaged; 3 drowned attempting to drive automobiles over submerged roads.	Do.
Warren County, Miss.	31	8:15 a.m.			900	Wind	No details	Do.
Marks, Miss.	31	8:20 a.m.			10,000	do	do	Do.
Plymouth, Springfield, and Algoma, Miss.	31	9:00 a.m.			14,500	do	do	Do.
Zachary to Darlington, La.	31	9:55–11a.m.	66	3	55,000	Tornado	15 persons injured and property damaged; path 40 miles long.	Do.
West Point, Miss.	31	10 a.m.		5	7,500	Wind	No details	Do.
Sherman, Miss.	31	10:30 a.m.		2	1,000	do	do	Do.
Lacombe to Pearl River section, La.	31	12 a.m.	70		17,000	Tornado	Damage mostly to buildings; path 20 miles long	Do.
Fletcher, Okla.	31	5 p.m.	440		6,000	do	Property damaged	Do.
Brewton, Ala. (7 miles northwest of).	31	5:15 p.m.	75		125,000	do	Turpentine camp demolished; 40 persons injured; 13 houses destroyed; path 6 miles long.	Do.
Perdido Bay to mouth of Escambia River, Fla.	31	7:30 p.m.	150		1,000	Tornadic winds	Church destroyed; dwelling partially destroyed, barn blown in; trees uprooted; 8 persons injured.	Do.
Choctawhatchee National Forest, Fla.	31	9:30 p.m.	880–2640		1,100	Tornado	Only 1 farm in path and no one injured; path zigzag and about 35 miles long.	Do.
Southern Baldwin County, Ala.	18	p.m.	300		10,000	do	Property damaged; path about 6 miles long	Do.
Knoxville, Tenn.	31				500	Wind	Barn loft caved in; airport hangar razed	Do.

[1] Miles instead of yards.

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Chart I. Departure (°F.) of the Mean Temperature from the Normal, March, 1933

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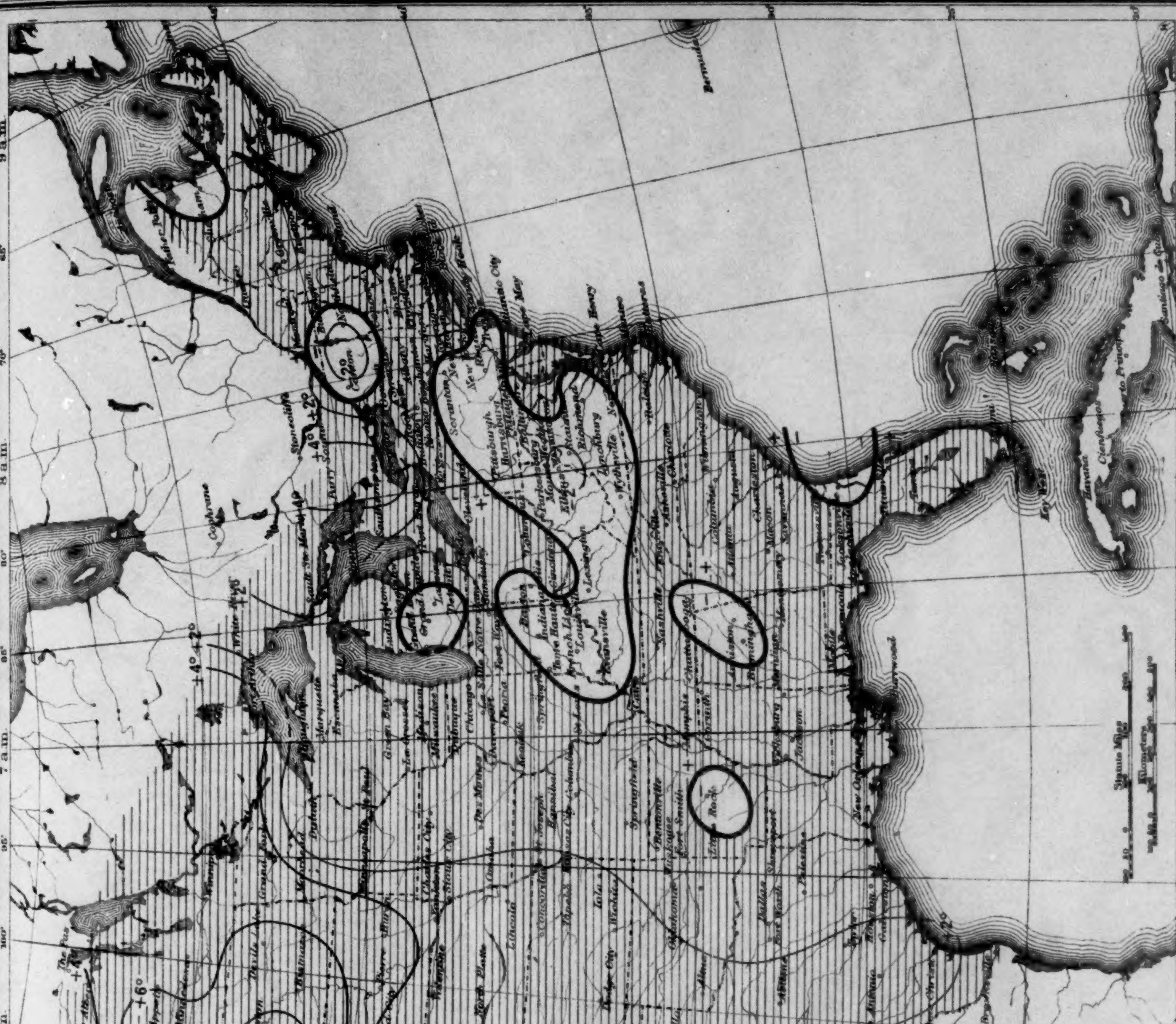
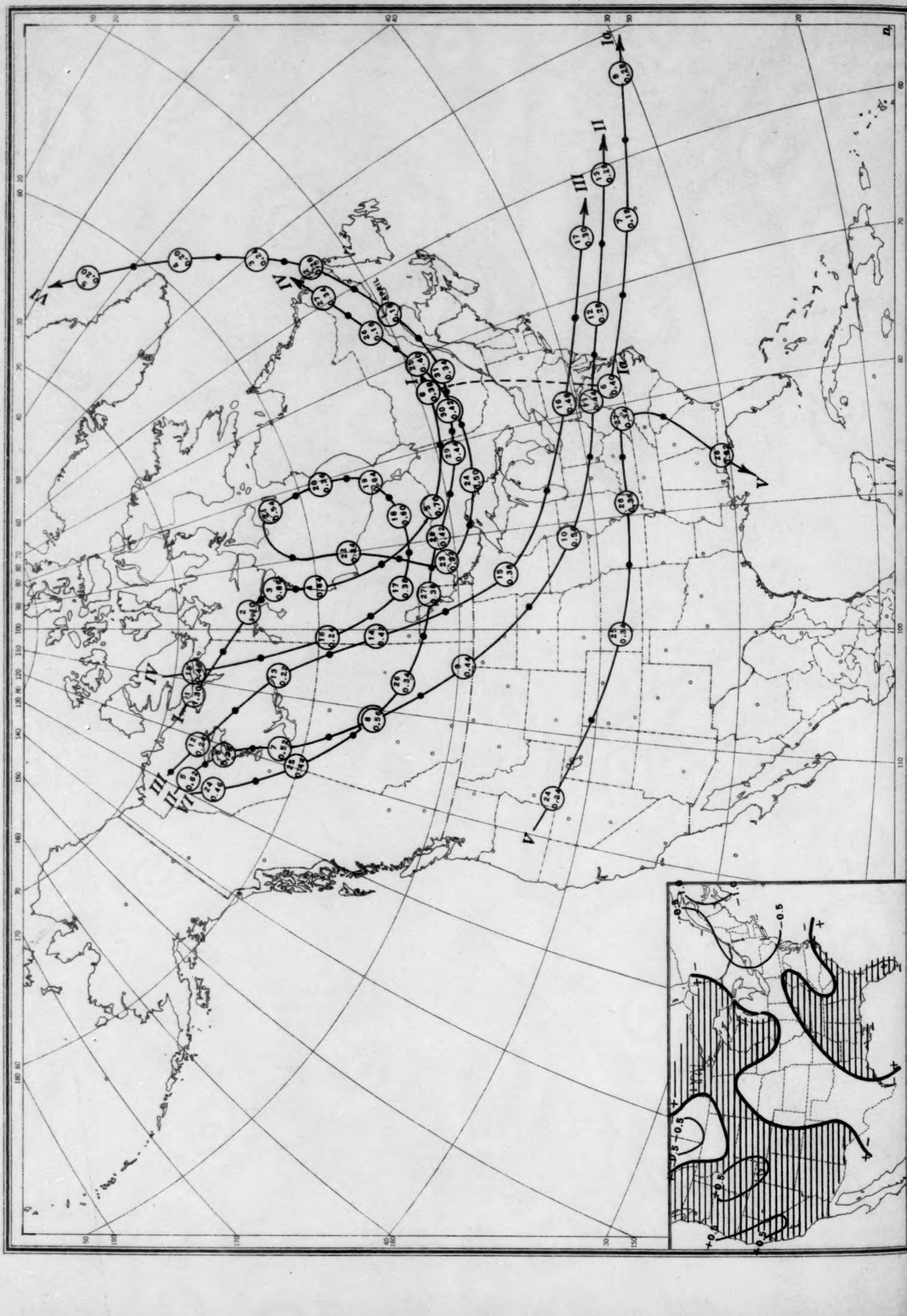


Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

Chart II. Tracks of Centers of Anticyclones, March, 1933. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by G. E. Dunn)



Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

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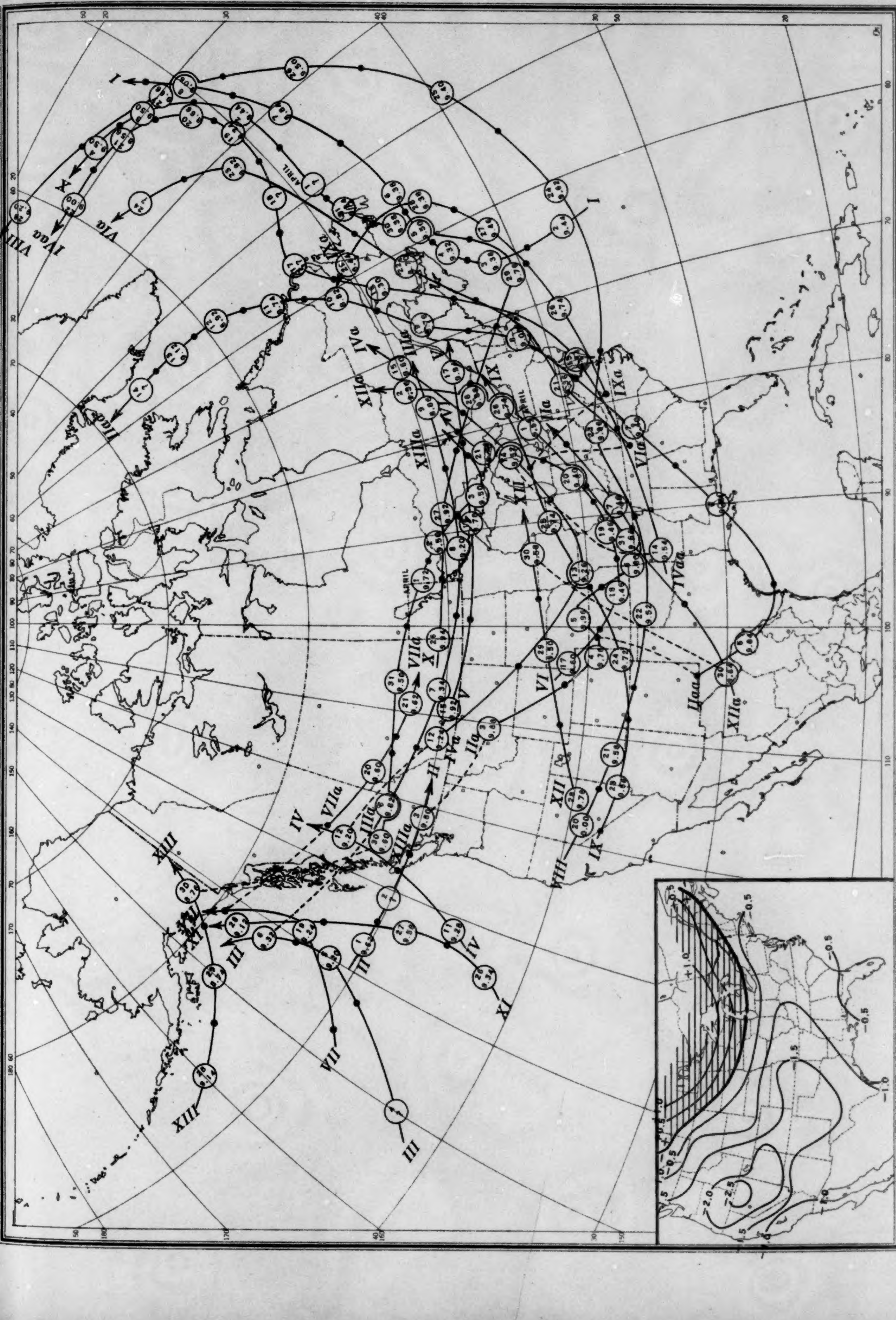
Chart III. Tracks of Centers of Cyclones, March, 1933. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by G. E. Dunn)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, March, 1933

Chart V. Total Precipitation, Inches, March, 1933. (Inset) Departure of Precipitation from Normal

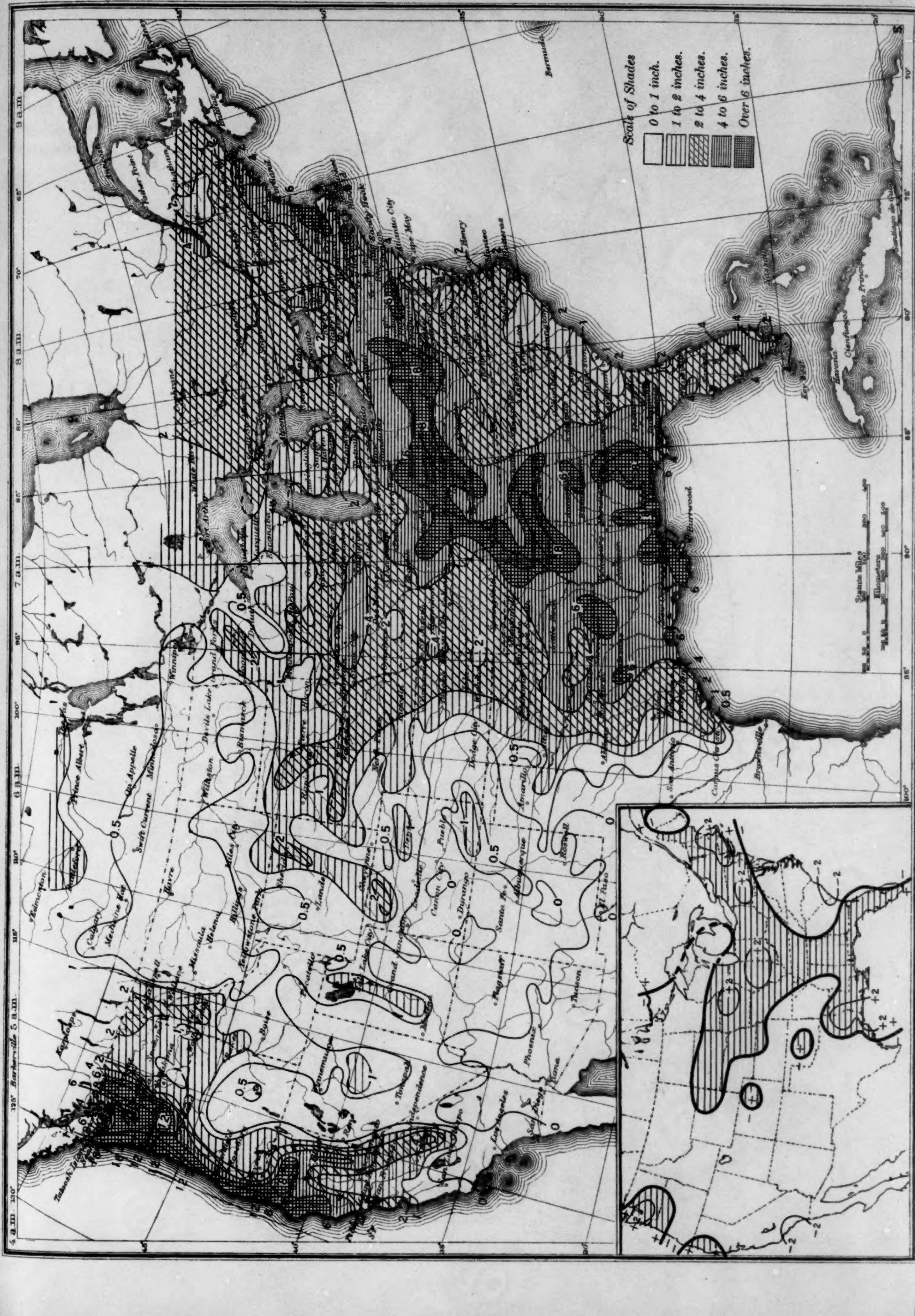


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, March, 1933

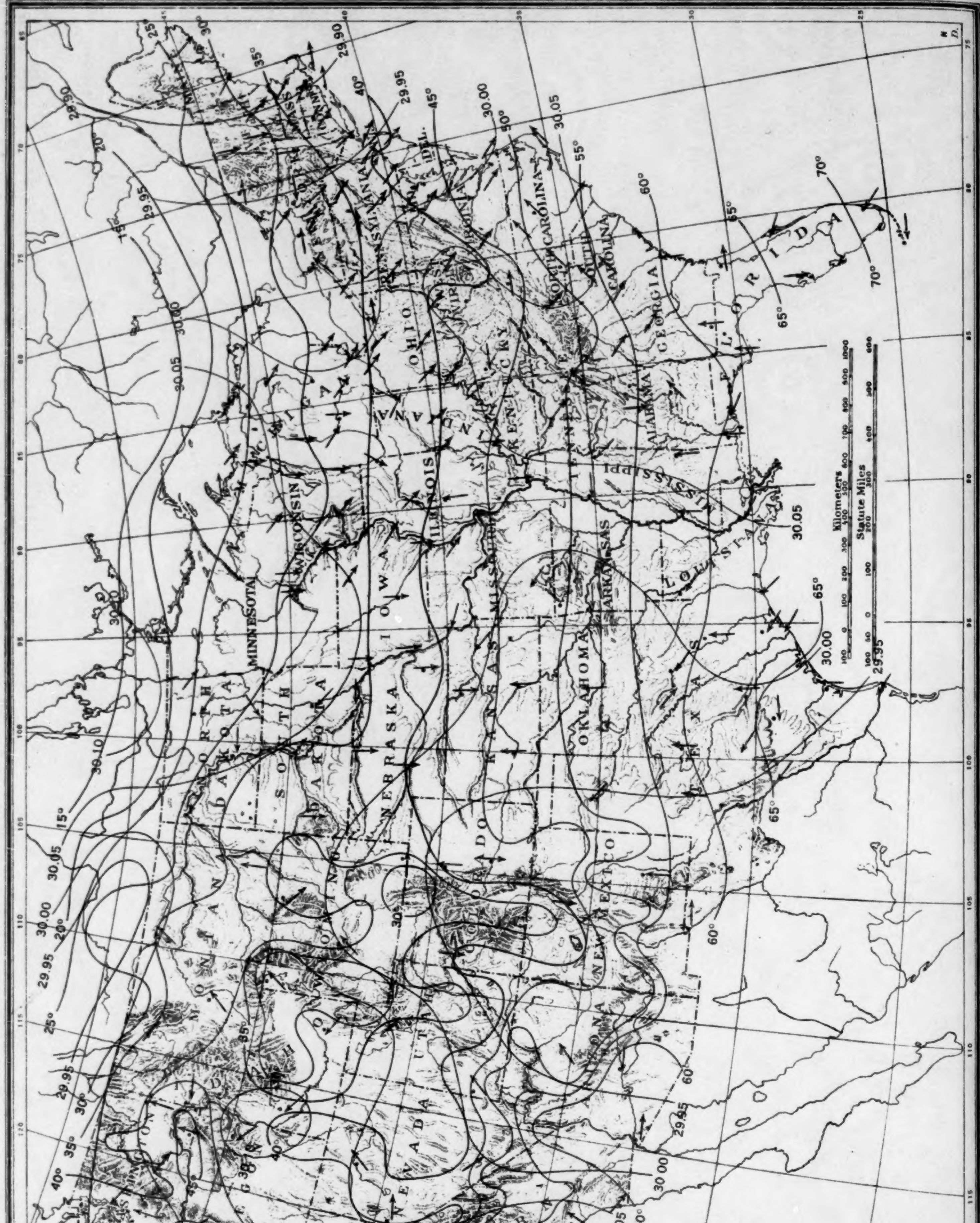


Chart VII. Total Snowfall, Inches, March, 1933. (Inset) Depth of Snow on Ground at 8 p.m., Monday, March 27, 1933

Chart VII. Total Snowfall, Inches, March, 1933. (Inset) Depth of Snow on Ground at 8 p. m., Monday, March 27, 1933

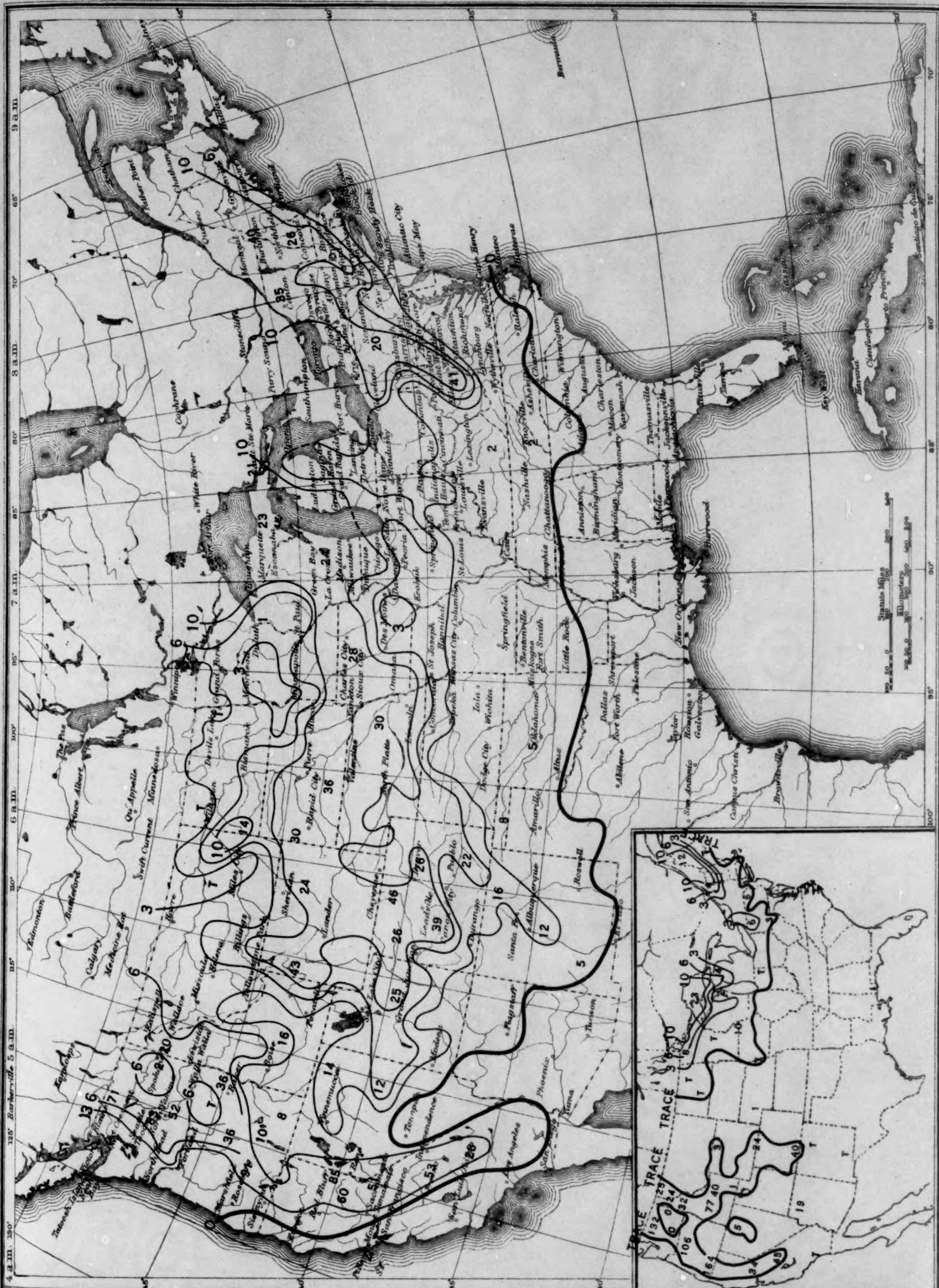


Chart VIII. Weather Map of North Atlantic Ocean, March 13, 1933
(Plotted from the Weather Bureau Northern Hemisphere Chart)

Chart VIII. Weather Map of North Atlantic Ocean, March 13, 1933

(Plotted from the Weather Bureau Northern Hemisphere Chart)

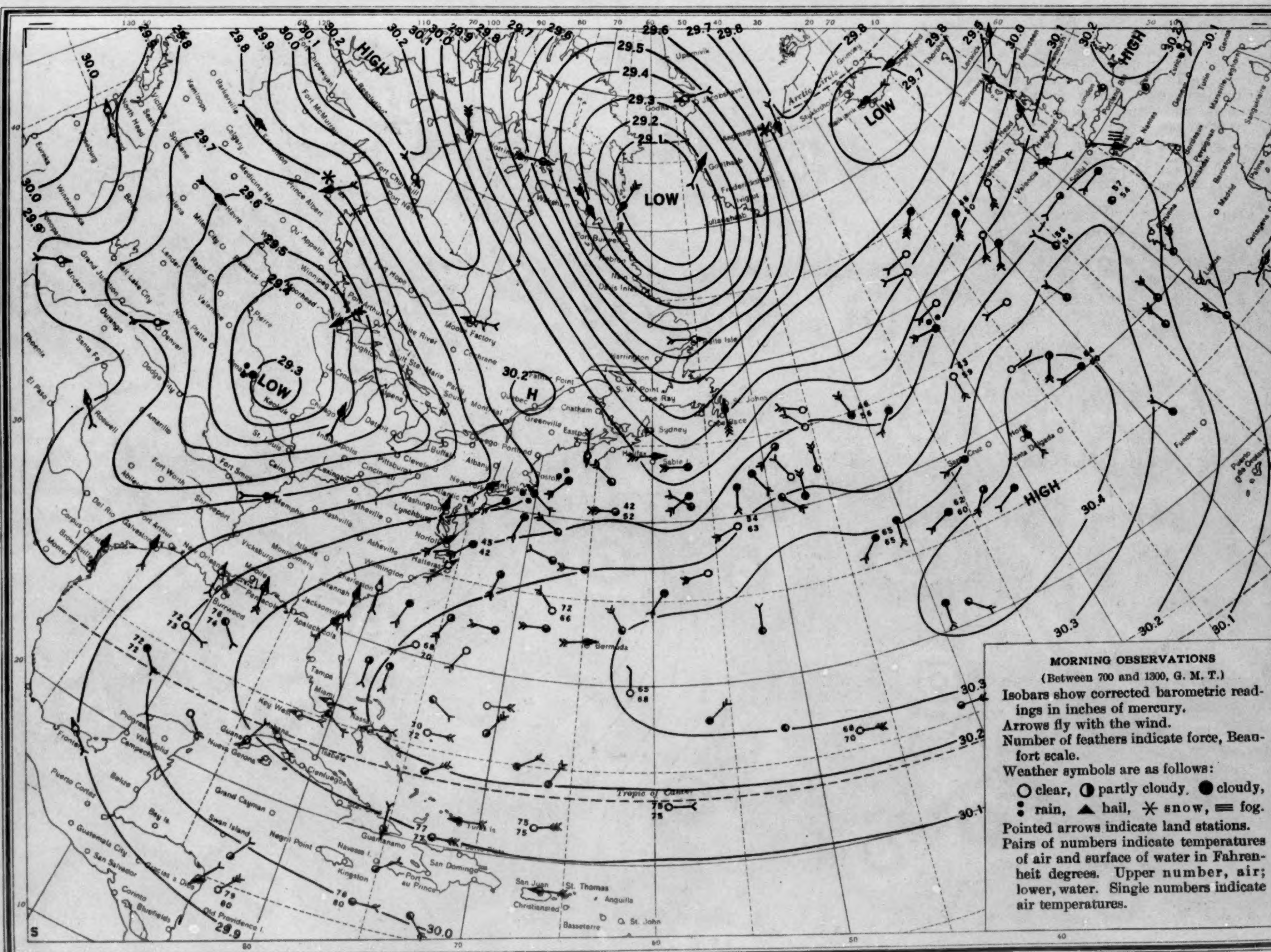


Chart IX. Weather Map of North Atlantic Ocean, March 20, 1933

(Plotted from the Weather Bureau Northern Hemisphere Chart)